REMARKS

Claims 1 through 13 are pending in this Application. Fig. 2 has been amended to address a manifest typographical oversight observed by the Examiner. In addition, claims 1 and 5 have been amended. Care has been exercised to avoid the introduction of new matter. Indeed, adequate descriptive support for the present Amendment should be apparent throughout the originally filed disclosure. Applicants submit that the present Amendment does not generate any new matter issue.

The Specification

The Examiner objected to the disclosure initially asserting that in the first paragraph under Example 2 a drawing rate of 8m/s stated; whereas, in Fig. 2, the drawing rate indicated is 4m/s. In response Fig. 2 has been amended (Exhibit A hereto) to correct the manifest typographical error observed by the Examiner. The Examiner's perspicacity is appreciated.

The Examiner also referred to Comparative Example 3, questioning the justification for the statement that the transmission loss of the Ge-containing fiber is reduced. In response Applicants would clarify that, generally, the transmission loss (with respect to light having a wavelength of 1.5 μ m) of a single-mode optical fiber of the prior art is greater than about 0.189 dB/km, as should be apparent from the Examiner's reference to Guenot et al. in the Table appearing at column 7 thereof. So when Applicants disclosed that the transmission loss of Example 2 was reduced, the reduction was as compared with a single-mode optical fiber of the prior art. Based upon this clarification, Applicants submit that the objection to the specification is not viable and, hence, solicit withdrawal thereof.

Claims 9, 11 and 13 were rejected under 35 U.S.C. §102 for lack of novelty as evidenced by JP2000-128566 issued to Okubo et al. (Okubo '566).

In the statement of the rejection the Examiner asserted that Okubo '566 discloses a method and apparatus corresponding to those claimed. This rejection is traversed.

As appreciated by the Examiner in the ultimate paragraph on page 3 of the November 19, 2003 Office Action, the effective date of Okubo '566 is May 9, 2000, subsequent to the filing date to which Applicant is entitled by virtue of 35 U.S.C. §119. Submitted herewith as Exhibit B is a certified English language copy of the foreign priority document P1999-289734, which has a filing date of October 19, 1999, clearly antedating Okubo '566. Accordingly, Okubo '566 is not prior art with respect to the claimed invention. This being the case, the imposed rejection under 35 U.S.C. §102 is not factually or legally viable.

Based upon the foregoing Applicants submit that the imposed rejection of claims 9, 11 and 13 under 35 U.S.C. §102 for lack of novelty as evidenced by Okubo '566 is not factually or legally viable and, hence, solicit withdrawal thereof.

Claims 1 through 8 were rejected under 35 U.S.C. §103 for obviousness predicated upon Van Der Giessen et al. in view of JP11-116264 issued to Okubo et al. or Okubo '566.

This rejection is traversed.

To whatever extent the imposed rejection is predicated upon Okubo '566, such rejection is not factually or legally viable because, as previously established, Okubo '566 is not prior art with respect to the claimed invention.

Applicants further submit that neither Van Der Giessen et al. nor Okubo et al. (JP11-116264) disclose or suggest an apparatus or method corresponding to those claimed wherein an

optical fiber preform is drawn in an atmosphere constituted by the first gas and wherein the drawn optical fiber is annealed in an atmosphere constituted by the second gas whose thermal conductivity is lower than that of the first gas. Indeed, in Okubo et al., He gas is introduced into a drawing furnace (3) from an inlet (5a) and is discharged from an exhaust port (6a). As a result, He gas and Ar gas are mixed in the region "A" of the drawing furnace (Exhibit C hereto). In other words, Okubo et al. do not disclose a heating furnace disposed between the drawing furnace and a resin coating section, nor the use of a second gas in the heating furnace. Okubo et al. merely disclose a first gas which constitutes an atmosphere in the drawing furnace, which is a mixture of He and Ar.

Based upon the foregoing it should be apparent that neither Van Der Giessen et al. nor Okubo et al. disclose or suggest an apparatus or method wherein an optical fiber preform is drawn in an atmosphere constituted by a first gas and then the drawn optical fiber is annealed in an atmosphere constituted by a second gas with a thermal conductivity lower than that of the first gas. Accordingly, even if the applied references are combined, the claimed invention would not result. *Uniroyal, Inc. v. Rudkin-Wiley Corp., 837 F.2d 1044, 5 USPQ2d 1434 (Fed. Cir. 1988).*

Applicants, therefore, submit that the imposed rejection of claims 1 through 8 under 35 U.S.C. §103 for obviousness predicated upon Van Der Giessen et al. in view of Okubo et al. or Okubo '566 is not factually or legally viable and, hence, solicit withdrawal thereof.

Claim 1 through 9 and 11 through 13 were rejected under 35 U.S.C. §103 for obviousness predicated upon Bailey et al. in view of Okubo et al. and Okubo '566.

This rejection is traversed.

Initially, as previously pointed out, Okubo '566 is not prior art with respect to the claimed invention. Accordingly, to the extent that the imposed rejection relies upon Okubo '566, the imposed rejection is not factually or legally viable.

Moreover, Applicants would point out that neither Bailey et al. nor Okubo et al. disclose or suggest a method or apparatus wherein an optical fiber perform is drawn in an atmosphere constituted by a first gas and then the drawn optical fiber is annealed in an atmosphere constituted by a second gas whose thermal conductivity is lower than that of the first gas. As previously pointed out with respect to Exhibit C, Okubo et al. merely disclose the use of a first gas in a drawing furnace which is a mixture of He and Ar. Okubo et al. neither disclose nor suggest a heating furnace disposed between the drawing furnace and a resin coating section, or the use of a second gas in the heating furnace. Accordingly, even if the applied references are combined, the claimed invention would not result. *Uniroyal, Inc. v. Rudkin-Wiley Corp., supra.*

Applicants, therefore, submit that the imposed rejection of claims 1 through 9 and 11 through 13 under 35 U.S.C. §103 for obviousness predicated upon Bailey et al. in view of Okubo et al. and Okubo '566 is not factually or legally viable and, hence, solicit withdrawal thereof.

Claims 1 through 13 were rejected under 35 U.S.C. §103 for obviousness predicated upon Ohga et al. in view of Okubo et al. and Okubo '566.

This rejection is traversed.

Again, Okubo '566 is not prior art with respect to the claimed invention. Accordingly, to the extent that the imposed rejection relies upon Okubo '566, the imposed rejection is not factually or legally viable.

Further, Applicants would point out that neither Ohga et al. nor Okubo et al. disclose or suggest a method or apparatus wherein an optical fiber preform is drawn in an atmosphere constituted by a first gas, and then the drawn optical fiber is annealed in an atmosphere constituted by a second gas having a thermal conductivity lower than that of the first gas. Ohga et al. disclose a method and apparatus where nitrogen gas is supplied to the drawing furnace as the first gas (column 1, line 32). Ohga et al. disclose that He, H_2 or O_2 is supplied in the heating furnace as the second gas (column 4, line 53, column 5, line 29, column 5, line 50 and column 5, line 66). However, all of the second gases disclosed by Ohga et al. have a higher thermal conductivity than the first gas, not a lower thermal conductivity than the first gas as required in the claimed invention.

As previously pointed out, Okubo et al. merely disclose the use of a first gas which is a mixture of He and Ar. Okubo et al. neither disclose nor suggest a heating furnace disposed between the drawing furnace and a resin coating section, or use of a second gas in the heating furnace.

Based upon the foregoing it should be apparent that even if the applied references are combined, the claimed invention would not result. *Uniroyal, Inc. v. Rudkin-Wiley Corp., supra*. Applicants, therefore, submit that the imposed rejection of claims 1 through 13 under 35 U.S.C. §103 for obviousness predicated upon Ohga et al. in view of Okubo et al. and Okubo '566 is not factually or legally viable and, hence, solicit withdrawal thereof.

Based upon the foregoing it should be apparent that the objections and rejections have been overcome and that all pending claims are in condition for immediate allowance. Favorable consideration is, therefore, respectfully solicited.

To the extent necessary, a petition for an extension of time under 37 C.F.R. 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account 500417 and please credit any excess fees to such deposit account.

Respectfully submitted,

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Replacement Sheet

FIG.2

	1ST GAS	2ND GAS	DRAWING RATE (m/s)	TENSION (N)	HEATING FURNACE TEMPERATURE (C°)	ENTERING TEMPERATURE (C°)	AVERAGE COOLING RATE (C°/s)	TRANSMISSION LOSS (dB/km)	RAYLEIGH SCATTERING COEFFICIENT (db μ m^{r}/km)	GLASS DIAMETER FLUCTUATION (μ m)
EXAMPLE1	He	N_2	4	0.245	1400	1600	600~800	0.170	0.84	±0.1
EXAMPLE2	He	N_2	8	0.785	1400	1600	500~700	0.182	0.92	±0.1
COMPARATIVE EXAMPLE1	He	He	4	0.245	—	—	ABOUT 30000	0.18	0.9	—
COMPARATIVE EXAMPLE2	He	N_2	4	0.245	—	—	ABOUT 4000~5000	0.174.	0.86	—
COMPARATIVE EXAMPLE3	He	N_2	4	0.245	1400	—	—	0.170	0.84	±0.3

CERTIFICATE OF VERIFICATION

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state that the attached documents are a true and complete translation to the best of my knowledge of Japanese Patent Application No. 289734/1999.

Dated this 2nd day of February, 2004

Signature of translator: Shiro Terasaki

Shiro TERASAKI

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: October 12,1999

Application Number: Japanese Patent Application No.289734/1999

Applicant(s): SUMITOMO ELECTRIC INDUSTRIES, LTD.

Commissioner,

Patent Office (Seal)

(Document Name) Patent Application

(Reference Number) 099Y0213

(Presentation Date) October 12,1999

(Directly) Commissioner of the Patent Office

(IPC) C03B 37/027

G02B 6/00

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(Lists of the Article to be presented)

(Name of Article) Specification 1

(Name of Article) Drawing 1

(Name of Article) Abstract 1

(General Power of Attorney Number) 9908938

(Proof Reading) Required

[TYPE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] Apparatus and Method for Making Optical Fiber

[SCOPE OF CLAIMS]

[Claim 1] A method of making an optical fiber, which draws an optical fiber preform upon heating; said method comprising the steps of:

using a drawing furnace for drawing said optical fiber preform in an atmosphere constituted by a first gas and a heating furnace, disposed with a gap with respect to said drawing furnace, for heating and annealing in an atmosphere constituted by a second gas said optical fiber drawn by said drawing furnace;

forming said gap between said drawing furnace and said heating furnace into a gas mixture layer in which said first and second gases exist in a mixed state;

feeding said optical fiber drawn by said drawing furnace to said heating furnace by way of said gas mixture layer; and

heating said drawn optical fiber in said heating furnace such that said optical fiber has a temperature within the range of 1200 to 1700°C.

[Claim 2] A method of making an optical fiber according to claim 1, wherein a barrier for separating said gas mixture layer from the outside air is provided,

said barrier being formed with a gas exit section for

letting out at least said first gas.

[Claim 3] A method of making an optical fiber according to claim 1 or claim 2, wherein a gas having a thermal conductivity on a par with or lower than that of said first gas is used as said second gas.

[Claim 4] A method of making an optical fiber according to one of Claims 1 to 3, wherein said drawn optical fiber has an entering temperature within the range of 1400 to 1900°C with respect to said gas mixture layer.

[Claim 5] An apparatus for making an optical fiber, which draws an optical fiber preform upon heating; said apparatus comprising:

a drawing furnace for drawing said optical fiber preform upon heating in an atmosphere constituted by a first gas; and

a heating furnace, disposed with a gap with respect to said drawing furnace, for heating said drawn optical fiber in an atmosphere constituted by a second gas such that said optical fiber attains a temperature within the range of 1200 to 1700°C;

wherein said gap between said drawing furnace and said heating furnace is formed into a gas mixture layer in which said first and second gases exist in a mixed state.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a method and apparatus for making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[0002]

[Prior Art]

As a method of making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering loss, one disclosed in Japanese Patent Application Laid-Open No. HEI 10-25127 has been known, for example. In this manufacturing method, an optical fiber preform is drawn upon heating so as to prepare an intermediate optical fiber, which is then reheated so as to be subjected to a heat treatment, whereby the reheating lowers the virtual temperature (the temperature to which the randomness of the state of atomic arrangement within the glass corresponds) due to the structural relaxation (rearrangement of atoms) in the glass, thus reducing its Rayleigh scattering intensity.

[0003]

[Problem to be Solved by the Invention]

However, the surface of the optical fiber immediately after drawing is coated with a UV resin or the like in order to protect the heated and drawn optical fiber. The above-mentioned method of making an optical fiber disclosed in Japanese Patent Application Laid-Open No. HEI 10-25127 is not suitable for mass-producing coated optical fibers,

since the resin coated on the optical fiber surface is burned by the heat at the time of reheating. Though the optical fiber may be reheated while in an uncoated state, it is not applicable as a mass-producing method due to damages at the time of handling the optical fiber and the like.

[0004]

In view of the points mentioned above, it is an object of the present invention to provide a method and apparatus for making an optical fiber, which is applicable to the mass production of coated optical fibers when making optical fibers whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[0005]

[Means for Solving the Problem]

The inventors diligently studied apparatus and methods for making an optical fiber applicable to the mass production of coated optical fibers and, as a result, have newly found the following fact concerning the relationship between the Rayleigh scattering intensity and the cooling rate of optical fibers after drawing.

[0006]

Within the glass at a higher temperature, atoms are vigorously vibrating due to thermal energy, whereby the atomic arrangement is in a state more random than that in the glass at a lower temperature. When the glass at a higher temperature is cooled slowly, atoms are cooled while being

arranged with a randomness corresponding to each temperature within the temperature range in which the atoms are allowed to be rearranged, whereby the randomness of atoms within the glass attains a state corresponding to the lowest temperature (1200°C) at which the structural relaxation proceeds. When the glass at a higher temperature is drastically cooled, however, it is cooled and fixed before the atomic arrangement reaches an equilibrium state corresponding to each temperature, whereby the atomic arrangement attains a state more random than that in the case annealed. The Rayleigh scattering intensity becomes higher as the atomic arrangement is more random even in the same material. Optical fibers which are usually cooled at a cooling rate of 5000 to 30000°C/s after the drawing are presumed to have an atomic arrangement more random than that in bulk glass, thus yielding a state with a higher virtual temperature, thereby increasing the Rayleigh scattering intensity.

[0007]

Since the time required for structural relaxation becomes longer as the temperature is lower, on the other hand, the structural relaxation does not occur until the temperature is maintained for several tens of hours at about 1200°C, for example. Since an optical fiber after drawing is usually cooled from about 2000°C to about 400°C in a fraction of a second, it is necessary for the optical fiber

to be annealed in a state having a temperature higher than 1200°C in order to lower the virtual temperature so as to make it approach 1200°C in a short period of time during which the optical fiber in the drawing step is cooled.

[0008]

Therefore, taking account of the optical fiber temperature and cooling rate after drawing, the inventors investigated the relationship between the cooling rate and Rayleigh scattering coefficient in a part where the temperature ranged from 1200 to 1700°C, thus being higher than the lowest temperature (about 1200°C) at which the above-mentioned structural relaxation proceeded but lower than 1700°C at which the structural relaxation proceeded in a very short period of time. As a result, it has been verified that the relationship indicated by Fig. 5 exists between the cooling rate and Rayleigh scattering coefficient in the part where the temperature of the optical fiber ranges from 1200 to 1700°C. As represented by the following expression (1), the Rayleigh scattering intensity (I) has such a property that it is inversely proportional to the fourth power of wavelength (λ):

$$I = A/\lambda^4 \qquad (1)$$

where the coefficient A is defined as the Rayleigh scattering coefficient.

[0009]

These results have proved that, if the cooling rate

of an optical fiber drawn upon heating, the portion of optical fiber where the temperature of the optical fiber is 1200 to 1700°C in particular, is slowed down in a predetermined segment, the Rayleigh scattering intensity of the optical fiber can be reduced, so as to lower the transmission loss.

[0010]

Also, the inventors have newly found the following facts. A heating furnace for heating and annealing the optical fiber drawn by the drawing furnace may be disposed in order to slow down the cooling rate in a predetermined segment in a part where the optical fiber has a temperature of 1200 to 1700°C. When this heating furnace is disposed so as to be directly connected to the drawing furnace, however, the dust occurring within the drawing furnace may enter the heating furnace and attach to the optical fiber within the heating furnace, thereby causing such problems as "spike" by which the glass diameter of the optical fiber changes temporarily, and the decrease in strength of the optical fiber. Examples of the dust occurring within the drawing furnace include (1) those occurring due to the wear and deterioration of the muffle tube in the drawing furnace, (2) those occurring upon recrystallization of volatile components in the optical fiber preform, (3) those generated upon reactions of the volatile components in the optical fiber preform with constituents of the muffle tube, (4) those occurring upon reactions with these products with gases

flowing through the muffle tube of the drawing furnace, and the like.

[0011]

When the heating furnace is not directly connected to the drawing furnace but disposed with a gap with respect to the drawing furnace, the cooling of the optical fiber may become uneven since the optical fiber let out of the drawing furnace is under the influence of the turbulence of outside air flows before entering the heating furnace, thereby causing such a problem as "glass diameter fluctuation" in which the glass diameter of the optical fiber periodically changes, or the deterioration in bending of the optical fiber.

[0012]

In view of such results of studies, the present invention provides a method of making an optical fiber, which draws an optical fiber preform upon heating; the method comprising the steps of using a drawing furnace for drawing the optical fiber preform in an atmosphere constituted by a first gas and a heating furnace, disposed with a gap with respect to the drawing furnace, for heating and annealing in an atmosphere constituted by a second gas the optical fiber drawn by the drawing furnace; forming the gap between the drawing furnace and the heating furnace into a gas mixture layer in which the first and second gases exist in a mixed state; feeding the optical fiber drawn by the drawing furnace

to the heating furnace by way of the gas mixture layer; and heating the drawn optical fiber in the heating furnace such that the optical fiber has a temperature within the range of 1200 to 1700°C.

[0013]

In the method of making the optical fiber according to the present invention, since the drawn optical fiber is heated in the heating furnace such that the optical fiber has a temperature within the range of 1200 to 1700°C, the cooling rate of the optical fiber drawn upon heating in the part where the optical fiber has a temperature within the range of 1200 to 1700°C is slowed down in a predetermined segment, whereby the optical fiber is annealed. Therefore, the virtual temperature of the optical fiber decreases, so that the randomness in atomic arrangement is reduced, whereby it is possible to make, in a very short period of time from the drawing upon heating to the resin coating, an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity. Since the Rayleigh scattering intensity is reduced by controlling the cooling rate of the optical fiber before being coated with a resin after being drawn, the heat treatment for reheating such as that in the above-mentioned prior art is unnecessary, whereby the method can be applied quite easily to the mass production of coated optical fibers whose surface is coated with a resin.

[0014]

Since the heating furnace is disposed with a gap with respect to the drawing furnace while the gap between the heating furnace and the drawing furnace is formed into a gas mixture layer in which the first and second gases exist in a mixed state, the dust occurring within the drawing furnace is restrained from entering the heating furnace, whereby the above-mentioned occurrence of "spike" or deterioration in the strength of the optical fiber can be suppressed. Also, since the gas mixture layer exists, the turbulence of outside air flows becomes less influential between the drawing furnace and the heating furnace, whereby the above-mentioned occurrence of "glass diameter fluctuation" or deterioration in bending of the optical fiber can be suppressed.

[0015]

It is preferable that a barrier for separating the gas mixture layer from the outside air is provided, whereas the barrier is formed with a gas exit section for letting out at least the first gas. Thus, when the barrier is provided, the turbulence in outside air flows becomes less influential, whereby the occurrence of "glass diameter fluctuation" or deterioration in bending of the optical fiber can further be suppressed. When the gas exit section for letting out at least the first gas is formed, the dust occurring within the drawing furnace is further restrained

from entering the heating furnace, whereby the above-mentioned occurrence of "spike" or deterioration in strength of the optical fiber can further be suppressed.

[0016]

Alternatively, it is preferable that a gas having a thermal conductivity on a par with or lower than that of the first gas is used as the second gas. Thus, when a gas having a thermal conductivity on a par with or lower than that of the first gas is used as the second gas, drawing can be carried out stably when an optical fiber preform having a relatively large diameter is used for drawing in particular, and an optical fiber whose transmission loss is lowered can be made.

[0017]

Alternatively, it is preferable that the drawn optical fiber has an entering temperature within the range of 1400 to 1900°C with respect to the gas mixture layer. Thus, when the drawn optical fiber has an entering temperature within the range of 1400 to 1900°C with respect to the gas mixture layer, the drawn optical fiber at a high temperature is annealed in the heating furnace, whereby the transmission loss of optical fiber can be lowered.

[0018]

The present invention provides an apparatus for making an optical fiber, which draws an optical fiber preform upon heating; the apparatus comprising a drawing furnace for

drawing the optical fiber preform upon heating in an atmosphere constituted by a first gas; and a heating furnace, disposed with a gap with respect to the drawing furnace, for heating the drawn optical fiber in an atmosphere constituted by a second gas such that the optical fiber attains a temperature within the range of 1200 to 1700°C; wherein the gap between the drawing furnace and the heating furnace is formed into a gas mixture layer in which the first and second gases exist in a mixed state.

[0019]

In the apparatus of making the optical fiber according to the present invention, since the drawn optical fiber is heated in the heating furnace such that the optical fiber attains a temperature within the range of 1200 to 1700°C, the cooling rate of the optical fiber in a part attaining a temperature of 1200 to 1700°C is slowed down in a predetermined segment, whereby the optical fiber is annealed. Therefore, the virtual temperature of the optical fiber decreases, so that the randomness in atomic arrangement is reduced, whereby it is possible to make, in a very short period of time from the drawing upon heating to the resin coating, an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity. Since the Rayleigh scattering intensity is reduced by controlling the cooling rate of the optical fiber before being coated with a resin after being drawn, the heat treatment for reheating

such as that in the above-mentioned prior art is unnecessary, whereby the apparatus can be applied quite easily to the mass production of coated optical fibers whose surface is coated with a resin.

[0020]

Since the heating furnace is provided with a gap with respect to the drawing furnace while the gap between the heating furnace and the drawing furnace is formed into a gas mixture layer in which the first and second gases exist in a mixed state, the dust occurring within the drawing furnace is restrained from entering the heating furnace, whereby the above-mentioned occurrence of "spike" or deterioration in strength of the optical fiber can further be suppressed. Also, since the gas mixture layer exists, the turbulence of outside air flows becomes less influential between the drawing furnace and the heating furnace, whereby the above-mentioned occurrence of "glass diameter fluctuation" or deterioration in bending of the optical fiber can be suppressed.

[0021]

[Embodiments of the Invention]

Embodiments of the present invention will be explained with reference to the drawings. In the explanation of the drawings, constituents identical to each other will be referred to with numerals identical to each other without repeating their overlapping descriptions.

[0022]

To begin with, a embodiment of the apparatus for making an optical fiber and a drawing apparatus used for the making method in accordance with the present invention will be explained with reference to Fig. 1.

[0023]

A drawing apparatus 1 is a drawing apparatus for silica type optical fibers, having a drawing furnace 11, a heating furnace 21 for annealing, and a resin curing section 31 which are disposed in this order in the drawing direction of an optical fiber preform 2 (downward in Fig. 1). The optical fiber preform 2 held by a preform supply apparatus (not depicted) is supplied to the drawing furnace 11, and the lower end of the optical fiber preform 2 is heated and softened by a heater 12 within the drawing furnace 11, whereby an optical fiber 3 is drawn. The drawing furnace 11 has a muffle tube 13 configured such that a gas supply passage 15 from a first gas supply section 14 is connected thereto, so that an atmosphere constituted by a first gas is attained within the muffle tube 13 of the drawing furnace 11. The optical fiber 3 drawn upon heating is cooled to about 1900°C by the first gas within the muffle tube 13. Thereafter, the optical fiber 3 is let out of the drawing furnace 11 from a muffle tube extension 16. As the first gas, inert gases such as N_2 gas and He gas can be used, for example. The thermal conductivity λ (T = 300 K) of N_2 gas is 26 mW/(m·K), whereas

the thermal conductivity λ (T = 300 K) of He gas is 150 mW/(m·K).

[0024]

The heating furnace 21 for annealing is disposed with a gap L1 with respect to the drawing furnace 11, and has a heater 22 and a muffle tube 23. The heating furnace 21 anneals a predetermined part of the optical fiber 3 at a predetermined cooling rate by heating the optical fiber 3 within the muffle tube 23 with the heater 22. The annealing in the heating furnace 21 for annealing is carried out such that a segment where the optical fiber 3 drawn upon heating yields a temperature difference of 50°C or more, e.g., a part where the temperature of the optical fiber 3 ranges from 1400 to 1600°C (a segment yielding a temperature difference of 200°C), in a portion where the temperature of the optical fiber 3 ranges from 1200 to 1700°C is annealed at a cooling rate of 1000°C/s or less. When the temperature of the furnace center is set so as to fall within the range of 1300 to 1600°C, a segment where the optical fiber 3 attains a temperature difference of 50°C or more is annealed at a cooling rate of 1000°C/s or less in the portion of optical fiber 3 yielding a temperature of 1400 to 1600°C.

[0025]

The installing positions of the heater 22 and core tube 23 in the heating furnace for annealing 21 and the total length thereof in the drawing direction of the optical fiber

preform 2 (in the vertical direction of Fig. 1) are set in view of the drawing speed such that the segment of optical fiber 3 yielding a temperature difference of 50°C or more in the portion of optical fiber 3 yielding a temperature of 1200 to 1700°C is located within the core tube 23 of the heating furnace for annealing 21 and annealed while being heated by the heater 22. Here, it is necessary to take account of the drawing speed because of the fact that the position yielding the same temperature in the optical fiber 3 shifts downward as the drawing speed increases. The temperature of the heater 22 in the heating furnace for annealing 21 is set such that the segment in which the optical fiber 3 located within the core tube 23 attains a temperature difference of 50°C or more is cooled at a cooling rate of 1000°C/s or less.

[0026]

The muffle tube 23 of the heating furnace 21 is configured so as to communicate with the outside air, whereby an atmosphere constituted by air (second gas) is attained within the muffle tube 23. The thermal conductivity λ (T = 300 K) of air is 26 mW/(m·K). A gas having a relatively large molecular weight such as N_2 or Ar can be used in place of air. When a gas such as N_2 or Ar is used as the second gas, the gas supply section as a source for supplying the second gas is configured so as to be connected to the muffle tube 23 by way of the gas supply passage.

[0027]

The heater 22 includes three heaters constituted by a first heater 22a, a second heater 22b, and a third heater 22c. The first heater 22a, second heater 22b, and third heater 22c are successively arranged in this order in the drawing direction of the optical fiber preform 2 (downward in Fig. 2). The respective temperatures of the heaters 22a, 22b, 22c are adjusted so as to satisfy:

$$T1 = T2 + 25°C \qquad (2)$$

$$T3 = T2 - 25°C \qquad (3)$$

where T1 is the surface temperature of the inner peripheral face of the muffle tube 23 at a position corresponding to the first heater 22a; T2 is the surface temperature of the inner peripheral face of the muffle tube 23 at a position corresponding to the second heater 22b; and T3 is the surface temperature of the inner peripheral face of the muffle tube 23 at a position corresponding to the third heater 22c. The temperature difference between T1 and T2 or the temperature difference between T2 and T3 is not restricted to 25°C, but may be about 30°C, for example. All the heaters may be set to the same temperature as well.

[0028]

When temperature differences are provide between the heaters 22a, 22b, 22c as mentioned above, a temperature gradient is formed within the muffle tube 23 of the heating furnace 21 for annealing such that the first heater 22a on

the drawing furnace 11 side and the third heater 22c on the resin curing section 31 side attain higher and lower temperatures, respectively. Therefore, the inside of the muffle tube 23 has a temperature distribution corresponding to the temperature distribution of the optical fiber 3 in which the temperature decreases from the drawing furnace 11 side to the resin curing section 31 side, whereby the temperature difference with respect to the optical fiber 3 can be kept more appropriately, and the optical fiber 3 can be cooled at a further suitable cooling rate.

[0029]

A buffer chamber 41 acting as a gas mixture layer is disposed between the muffle tube extension 16 and the heating furnace 21 for annealing, whereas the length of the buffer chamber 41 in the drawing direction of the optical fiber 3 is substantially L1 as shown in Fig. 1. A slight gap exists between the muffle tube extension 16 and the buffer chamber 41, so that the muffle tube extension 16 and the buffer chamber 41 are not directly connected to each other. The buffer chamber 41 is constituted by a first buffer cell 42 and a second buffer cell 45. In the inner space of the buffer chamber 41 (the first buffer cell 42 and second buffer cell 45), the first gas as the atmosphere gas within the drawing furnace 11 (muffle tube 13) and air as the atmosphere gas within the heating furnace 21 for annealing (muffle tube 23) exist in a mixed state. Here, the buffer chamber 41

(the first buffer cell 42 and the second buffer cell 45) constitutes the gas mixture layer in each claim.

[0030]

The first buffer cell 42 has a barrier 43 for separating the inner space, through which the optical fiber 3 passes, from the outside air, whereas the barrier 43 is formed with a plurality of exit holes 44 for letting out the first gas flowing from within the drawing furnace 11 and the dust occurring within the drawing furnace 11. The second buffer cell 45 has a barrier 46 for separating the inner space, through which the optical fiber 3 passes, from the outside air, whereas the barrier 46 is formed with a plurality of exit tubes 47 for letting out the second gas flowing from within the drawing furnace 11 and the dust occurring within the drawing furnace 11. The first buffer cell 42 and the second buffer cell 45 are separated from each other by a partition wall 48. The partition wall 48 is formed with an optical fiber passing hole 49 though which the optical fiber 3 passes. A supply tube for supplying N_2 gas and the like may be connected to the second buffer cell 45 so as to supply N_2 gas and the like from the supply tube, thereby positively letting out the first gas flowing from within the drawing furnace 11 and the dust occurring within the drawing furnace 11. Here, the exit holes 44 and the exit tubes 47 constitute the gas exit section in each claim.

[0031]

The optical fiber 3 let out of the drawing furnace 11 from the muffle tube extension 16 subsequently enters the buffer chamber 41 (the first buffer cell 42 and second buffer cell 45), and then enters the heating furnace 21 for annealing so as to be annealed therein while in a state restrained from coming into contact with the outside air by the buffer chamber 41 (the first buffer cell 42 and second buffer cell 45). The entering temperature of the optical fiber 3 with respect to the buffer chamber 41 (the first buffer cell 42) falls within the range of 1400 to 1900°C so as not to hinder a segment where the optical fiber 3 attains a temperature difference of 50°C or more in the portion of optical fiber 3 yielding a temperature of 1200 to 1700°C in the heating furnace 21 from being annealed.

[0032]

The outer diameter of the optical fiber 3 let out of the heating furnace 21 for annealing is measured online by an outer diameter meter 51, and its measured value is fed back to a driving motor (not depicted) for driving an optical fiber take-up device (not depicted) to rotate, whereby the outer diameter is controlled so as to become constant. Preferably, the outer diameter meter is installed downstream the heating furnace 21 as such. This is because of the fact that, if the outer diameter meter 51 is installed directly below the drawing furnace 11, the temperature of the optical fiber 3 will decrease there so much that effects of annealing

may be lost.

[0033]

Thereafter, the optical fiber 3 is cooled to about several ten °C by a forcible cooling unit 52. The forcible cooling unit 52 is configured such that a gas (e.g., He gas) at a room temperature or lower is caused to flow through a thin, elongated pipe through which the optical fiber 3 passes. The optical fiber 3 cooled by the forcible cooling unit 52 is coated with a UV resin 54 by a coating die 53, and the UV resin 54 is cured by a UV lamp 32 in the resin curing section 31, whereby a coated optical fiber 4 is obtained. By way of a guide roller 61, the coated optical fiber 4 is taken up by a drum. A thermosetting resin may be used in place of the UV resin 54, so as to be cured by the heating furnace.

[0034]

With reference to Fig. 2, results of experiments carried out by using the above-mentioned drawing apparatus 1 will now be explained. These experiments have the following common conditions. An optical fiber 3 having an outside diameter of 125 μm was drawn from the optical fiber preform 2. The temperature of the drawing furnace was such that the surface temperature of the inner peripheral face of the muffle tube (facing the surface of the optical fiber preform 2 or optical fiber 3) was about 2000°C, whereas the drawing rate was 400 m/min.

[0035]

Examples 1 to 3 are examples in conformity to the apparatus and method for making an optical fiber in accordance with the above-mentioned embodiment, whereas Comparative Examples 1 to 3 are comparative examples carried out for comparison with the above-mentioned Examples in conformity to the apparatus and method for making an optical fiber in accordance with the embodiment.

[0036]

(Example 1)

Using a heating furnace for annealing with a muffle tube having an inner peripheral diameter of 20 mm and a total length of 1500 mm, an optical fiber was drawn. As the first gas, N_2 gas was used. The optical fiber preform to be drawn was one having a core portion constituted by pure silica glass and a cladding portion constituted by fluorine-doped glass, whose outer diameter was 40 mm. The buffer chamber 41 had a length L1 of 100 mm in the drawing direction of the optical fiber 3, whereas the muffle tube extension 16 had a length L2 of 50 mm in the drawing direction of the optical fiber 3. The heating furnace had a temperature (at the furnace center) of about 1500°C. The temperature (entering temperature) of the optical fiber immediately before entering the heating furnace for annealing was supposed to be 1800°C in terms of the surface temperature of optical fiber. Therefore, in the heating furnace, the

part of drawn optical fiber where the temperature was 1800 to 1600°C was cooled at an annealing rate of about 890°C/s on average in a segment of 1500 mm which was the total length of the heating furnace.

[0037]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 μm) was 0.167 dB/km, whereas the Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.835 dBμm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.15 μm, whereby "glass diameter fluctuation" was ±0.15 μm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 0, whereas "bending abnormality ratio" was 0%. As for "bending abnormality ratio," the radius of curvature was measured at different positions of the optical fiber, parts yielding a predetermined radius of curvature (4.2 m in this Example) or greater were defined defective, and the ratio of the number of positions where defects were detected to the number n of measured positions (n = 10 in this Example) was expressed in terms of percentage.

[0038]

(Example 2)

Using a heating furnace for annealing with a muffle tube having an inner peripheral diameter of 20 mm and a total

length of 1500 mm, as in Example 1, an optical fiber was drawn. As the first gas, He gas was used. The optical fiber preform to be drawn was one having a core portion constituted by pure silica glass and a cladding portion constituted by fluorine-doped glass, whose outer diameter was 80 mm. The buffer chamber 41 had a length L1 of 100 mm in the drawing direction of the optical fiber 3, whereas the muffle tube extension 16 had a length L2 of 50 mm in the drawing direction of the optical fiber 3. The heating furnace had a temperature (at the furnace center) of about 1500°C. The temperature (entering temperature) of the optical fiber immediately before entering the heating furnace was supposed to be 1720°C in terms of the surface temperature of optical fiber. Therefore, in the heating furnace, the part of drawn optical fiber where the temperature ranged from 1720 to 1520°C was cooled at an annealing rate of about 890°C/s on average in a segment of 1500 mm which was the total length of the heating furnace.

[0039]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 μm) was 0.168 dB/km, whereas the Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.84 dBμm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.15 μm, whereby "glass diameter fluctuation"

was ±0.15 µm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 0, whereas "bending abnormality ratio" was 0%.

[0040]

(Comparative Example 1)

As shown in Fig. 3, an optical fiber was drawn in a configuration lacking the buffer chamber 41 (first buffer cell 42 and second buffer cell 45). Experiment conditions other than that were the same as those of Example 1.

[0041]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 µm) was 0.168 dB/km, whereas the Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.84 dBµm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.8 µm, whereby "glass diameter fluctuation" was ±0.8 µm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 0, whereas "bending abnormality ratio" was 20%.

[0042]

(Comparative Example 2)

As shown in Fig. 4, an optical fiber was drawn in a configuration in which the heating furnace 21 for annealing was directly connected to the muffle tube extension 16 in an airtight fashion. Experiment conditions other than that

were the same as those of Example 1. However, since the heating furnace 11 was directly connected to the drawing furnace 11, N_2 gas flowed into the heating furnace 21 for annealing (muffle tube 23) from the drawing furnace 11, whereby an atmosphere constituted by N_2 gas was attained within the heating furnace 21 for annealing (muffle tube 23).

[0043]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 μm) was 0.167 dB/km, whereas the Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.835 dBμm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.15 μm, whereby "glass diameter fluctuation" was ±0.15 μm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 12, whereas "bending abnormality ratio" was 0%.

[0044]

(Comparative Example 3)

An optical fiber was drawn in a state where no heating (annealing) was effected by the heating furnace 21 for annealing (heater 22) in the configuration of Comparative Example 2. Experiment conditions other than that were the same as those of Example 1. However, since the heating furnace 21 for annealing was directly connected to the

drawing furnace 11 as in Comparative Example 2, N_2 gas flowed into the heating furnace 21 for annealing (muffle tube 23) from the drawing furnace 11, whereby an atmosphere constituted by N_2 gas was attained within the heating furnace 21 for annealing (muffle tube 23).

[0045]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 μm) was 0.171 dB/km, whereas the Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.855 dBμm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.15 μm, whereby "glass diameter fluctuation" was ±0.15 μm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 1, whereas "bending abnormality ratio" was 0%.

[0046]

(Example 3)

An optical fiber was drawn while using He gas in place of air as the second gas in the configuration of Example 2. Experiment conditions other than that were the same as those of Example 2.

[0047]

Upon measurement, the transmission loss of the drawn optical fiber (with respect to light having a wavelength of 1.55 μm) was 0.169 dB/km, whereas the Rayleigh scattering

coefficient determined from measured data of wavelength characteristics of transmission loss was 0.845 dBμm^4/km. Upon measurement, the outer diameter of the drawn optical fiber was 125±0.15 μm, whereby "glass diameter fluctuation" was ±0.15 μm. The number of occurrences of "spike" per 1000 km of the drawn optical fiber was 0, whereas "bending abnormality ratio" was 0%.

[0048]

As in the foregoing, Examples 1 and 2 yielded a Rayleigh scattering coefficient of 0.835 to 0.84 dBμm^4/km and a transmission loss of 0.167 to 0.168 dB/km with respect to light having a wavelength of 1.55 μm, thereby lowering the Rayleigh scattering coefficient and reducing the transmission loss as compared with Comparative Example 3 yielding a Rayleigh scattering coefficient of 0.855 dBμm^4/km and a transmission loss of 0.171 dB/km with respect to light having a wavelength of 1.55 μm without annealing.

[0049]

Examples 1 to 3 yielded a "glass diameter fluctuation" of ±0.15 μm and a "bending abnormality ratio" of 0%, thereby suppressing the occurrence of "glass diameter fluctuation" and the deterioration in bending of the optical fiber as compared with Comparative Example 1 yielding a "glass diameter fluctuation" of ±0.8 μm and a "bending abnormality ratio" of 20%, in which the drawing was carried out in the state where the distance L1 was provided between the drawing

furnace 11 and heating furnace 12 for annealing while lacking the buffer chamber 41.

[0050]

In Examples 1 to 3, the number of occurrences of "spike" per 1000 km of the optical fiber was 0, whereby the "spike" was restrained from occurring as compared with Comparative Example 2 in which the number of occurrences of "spike" per 1000 km of the optical fiber was 12 while the drawing was carried out in the state where the drawing furnace 11 and the heating furnace 21 for annealing were directly connected to each other.

[0051]

Examples 2 and 3, in which the optical fiber preform to be drawn had a larger diameter (outer diameter of 80 mm), suppressed the occurrence of "glass diameter fluctuation" by using He gas as the first gas. It is presumed to be because of the fact that He gas having a higher thermal conductivity is more effective in suppressing the natural convection within the drawing furnace.

[0052]

The reason why Example 3 yielded a transmission loss greater than that of Example 2 is presumed to be because of the fact that, when He gas was caused to flow into the heating furnace, He gas did not reach its set temperature at the upper and lower ends of the furnace, whereby the optical fiber was suddenly cooled.

[0053]

The case where the heating furnace 21 for annealing is directly connected to the drawing furnace 11 (muffle tube extension 16) in an airtight fashion as shown in Fig. 4 yields problems as follows:

(1) In order to directly connect the heating furnace to the drawing furnace, the heating furnace must have a structure similar to that of the drawing furnace, whereby the apparatus has a larger scale (e.g., a carbon heater must be employed for cooling the furnace with water). Consequently, it becomes harder to maintain the heater, the muffle tube, and the like.

(2) When drawing an optical fiber preform having a larger diameter, it is preferred that He gas be used in the drawing furnace in order to stabilize the glass diameter, whereas N_2 gas or air be used in the heating furnace in order to suppress the cooling of fiber. When the drawing furnace and the heating furnace are directly connected to each other, however, the gas usable therein is limited to one species, whereby two kinds of gases cannot be used as mentioned above.

[0054]

As can be seen from the results of experiments mentioned above, since the apparatus and method for making an optical fiber in accordance with the embodiment is provided with the heating furnace 21 for heating the optical fiber 3 at a temperature within the range of 1200 to 1700°C before it

is coated with the UV resin 53 after being drawn upon heating in the drawing furnace 11, the cooling rate of the above-mentioned optical fiber 3 is slowed down in a predetermined segment in the portion where it attains a temperature of 1200 to 1700°C, so that the randomness in atomic arrangement is reduced, whereby it is possible to make the optical fiber 3 whose transmission loss is reduced by lowering the Rayleigh scattering intensity from the drawing upon heating to the coating with the UV resin 53. Also, since the Rayleigh scattering intensity is lowered by controlling the cooling rate of the optical fiber 3 before being coated with the UV resin 53 after being drawn, the heat treatment for reheating such as that in the above-mentioned prior art is unnecessary, whereby this embodiment can be applied quite easily to the mass production of the coated optical fiber 4 whose surface is coated with the UV resin 53 cured thereon.

[0055]

Since the heating furnace 21 for annealing is disposed with a gap L1 with respect to the drawing furnace 11, whereas the gap is formed into the buffer chamber 41 (first buffer cell 42 and second buffer cell 45) in which the first gas to become the atmosphere gas within the drawing furnace 11 (muffle tube 13) and the second gas to become the atmosphere gas within the heating furnace 21 for annealing (muffle tube 23) exist in a mixed state, the dust occurring within the

drawing furnace 11 is restrained from entering the heating furnace 21 for annealing, whereby the occurrence of "spike" or the deterioration in strength of the optical fiber 3 can be suppressed.

[0056]

Due to the existence of the buffer chamber 41 (first buffer cell 42 and second buffer cell 45), the turbulence of outside air flows becomes less influential between the drawing furnace 11 and the heating furnace 21, whereby the occurrence of "glass diameter fluctuation" or the deterioration in bending of the optical fiber 3 can be suppressed.

[0057]

Since the buffer chamber 41 (first buffer cell 42 and second buffer cell 45) has the barrier 43 formed with a plurality of exit holes 44 and the barrier 46 formed with a plurality of exit tubes 47, the turbulence of outside air flows can be suppressed more reliably, whereby the occurrence of "glass diameter fluctuation" or the deterioration in bending of the optical fiber 3 can further be suppressed. Since the first gas flowing from the drawing furnace 11 (muffle tube 13) side is discharged through the exit holes 44 and exit tubes 47, the dust occurring within the drawing furnace 11 is further restrained from entering the heating furnace 21 for annealing (muffle tube 23), whereby the occurrence of "spike" or the deterioration in strength of

the optical fiber 3 can further be suppressed.

[0058]

When a gas having a thermal conductivity on a par with or lower than that of the first gas is used as the second gas, in particular when He gas is used as the first gas while N_2 gas or air is used as the second gas, the optical fiber 3 with a lowered transmission loss can be made while the drawing can be carried out stably in the case where the optical fiber preform 2 having a relatively large diameter is used for drawing.

[0059]

Preferably, the entering temperature of the drawn optical fiber 3 with respect to the buffer chamber 41 (first buffer cell 42) falls within the range of 1400 to 1900°C. When the entering temperature of the drawn optical fiber 3 with respect to the buffer chamber 41 falls within the range of 1400 to 1900°C as such, the drawn optical fiber 3 enters the heating furnace 21 for annealing while in a high-temperature state, so that the drawn optical fiber 3 is annealed from the relatively high-temperature state in the heating furnace 21 for annealing, whereby the transmission loss of the optical fiber 3 can be lowered.

[0060]

Though the buffer chamber 41 is constituted by the first buffer cell 42 and second buffer cell 45 in the second embodiment, it is not restricted thereto but can be

constituted so as to provide one buffer cell or three or more buffer cells.

[0061]

As long as a gas mixture layer exists between the muffle tube extension 16 and the heating furnace 21 for annealing (muffle tube 23), it is not always necessary to provide the buffer chamber 41 itself. When the drawing furnace 11 (muffle tube extension 16) and the heating furnace 21 for annealing are disposed close to each other, e.g., the gap L1 between the drawing furnace 11 (muffle tube extension 16) and the heating furnace 21 for annealing is set to about 10 mm, the first gas to become the atmosphere gas within the drawing furnace 11 (muffle tube 13) and the second gas to become the atmosphere gas within the heating furnace 21 for annealing (muffle tube 23) are mixed so as to form a gas mixture layer in the space between the drawing furnace 11 and the heating furnace 21 for annealing, so that this space attains a state substantially separated from the outside air, thereby yielding effects similar to those obtained when the buffer chamber 41 is provided. In the case using He gas as the first gas in the configuration lacking the buffer chamber 41, the optical fiber 3 will be cooled if He gas invades the lower part, whereby it is preferred that a barrier or the like for preventing He gas from invading the lower part be provided. However, the configuration provided with the buffer chamber 41 is preferably employed

in view of the fact that it can make the pressure within the buffer chamber 41 higher than the outside pressure so that the turbulence of outside air flows can reliably be made less influential.

[0062]

Though the heater 22 of the heating furnace 21 for annealing is constituted by the first heater 22a, second heater 22b, and third heater 22c in the second embodiment, the number of heaters is not restricted thereto, whereby it may also be constituted by a single heater or four or more heaters.

[0063]

The present invention is applicable to the drawing of not only the optical fiber preform having a core portion constituted by pure silica glass and a cladding portion constituted by fluorine-doped glass used in the above-mentioned Examples but also Ge-doped optical fiber preforms having a core portion doped with Ge, for example.

[0064]

[Effects of the Invention]

As explained in detail in the foregoing, the present invention can provide an apparatus and method for making an optical fiber, which is applicable to the mass production of coated optical fibers, when making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[0065]

The dust occurring within the drawing furnace is restrained from entering the heating furnace, whereby the above-mentioned occurrence of "spike" or deterioration in the strength of the optical fiber can be suppressed. Also, since the gas mixture layer exists, the turbulence of outside air flows becomes less influential between the drawing furnace and the heating furnace, whereby the above-mentioned occurrence of "glass diameter fluctuation" or deterioration in bending of the optical fiber can be suppressed.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A schematic diagram showing an embodiment of the apparatus and method for making an optical fiber in accordance with the present invention.

[Fig. 2]

A table showing Examples in conformity to the embodiment of the apparatus and method for making an optical fiber in accordance with the present invention and Comparative Examples.

[Fig. 3]

A schematic diagram showing the apparatus and method for making an optical fiber in Comparative Example.

[Fig. 4]

A schematic diagram showing the apparatus and method for making an optical fiber in Comparative Example.

[Fig. 5]

A chart showing the relationship between Rayleigh scattering coefficient and optical fiber cooling rate.

[DESCRIPTION OF THE NUMERALS]

1 ··· a drawing apparatus, 2 ··· an optical fiber preform, 3 ··· an optical fiber, 4 ··· a coated optical fiber, 11 ··· a drawing furnace, 12 ··· a heater, 13 ··· a muffle tube, 14 ··· a first gas supply section, 15 ··· a gas supply passage, 16 ··· a muffle tube extension, 21 ··· an heating furnace, 22 ··· a heater, 23 ··· a muffle tube, 24 ··· an N_2 gas supply section, 25 ··· an N_2 gas supply passage, 31 ··· a resin curing section, 41 ··· A buffer chamber, 42 ··· a first buffer cell, 43 ··· a barrier, 44 ··· exit holes, 45 ··· a second buffer cell, 46 ··· a barrier, 47 ··· exit tubes, 48 ··· a partition wall, 49 ··· an optical fiber passing hole, 51 ···an outer diameter meter.

[TYPE OF DOCUMENT] ABSTRACT

[ABSTRACT]

[Problem] To provide a method for making an optical fiber, which is applicable to the mass production of coated optical fibers, when making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[Solving Means] A buffer chamber 41 acting as a gas mixture layer is disposed between the muffle tube extension 16 and the heating furnace 21 for annealing, whereas the length of the buffer chamber 41 in the drawing direction of the optical fiber 3 is substantially L1. The buffer chamber 41 is constituted by a first buffer cell 42 and a second buffer cell 45. In the inner space of the buffer chamber 41 (the first buffer cell 42 and second buffer cell 45), the first gas as the atmosphere gas within the drawing furnace 11 (muffle tube 13) and air as the atmosphere gas within the heating furnace 21 for annealing (muffle tube 23) exist in a mixed state.

[ELECTED FIGURE] Fig. 1

【TYPE OF DOCUMENT】 1/5
DORAWING

Fig.1

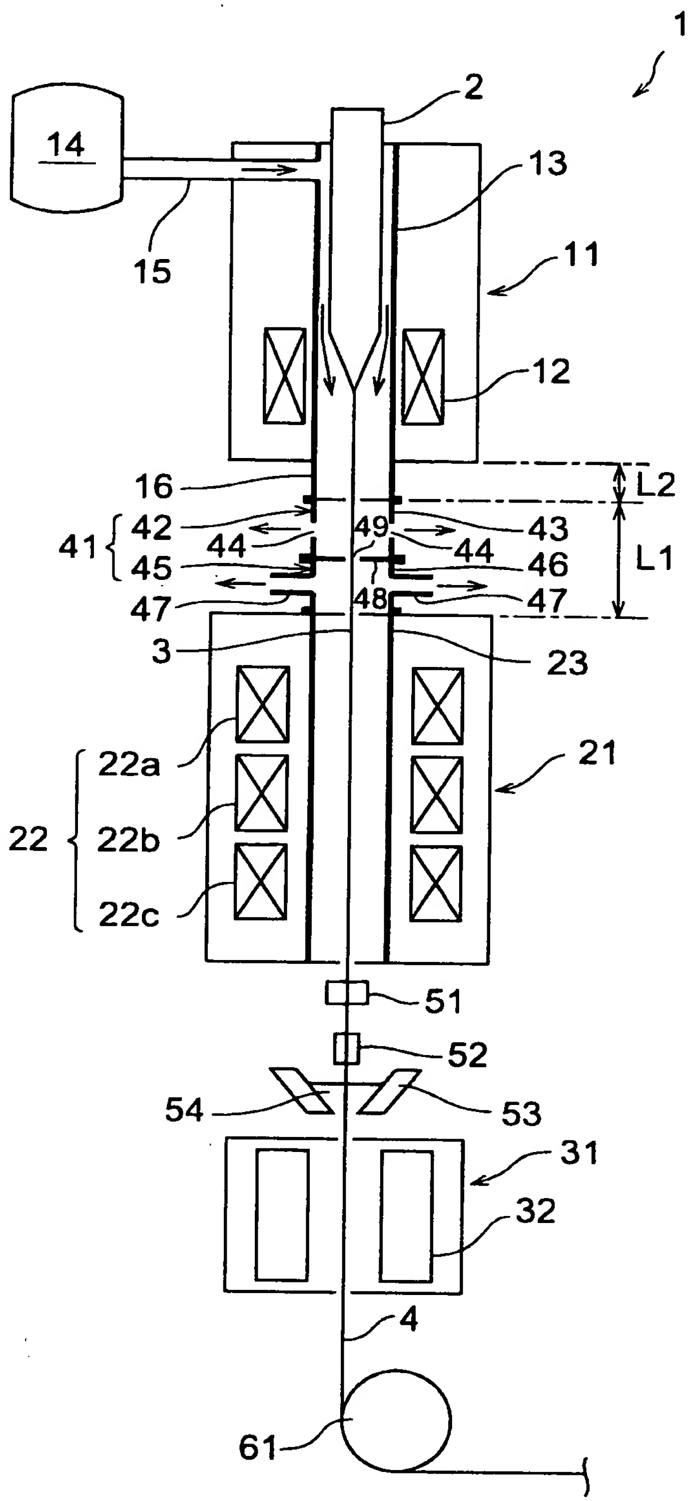


Fig.2

	OPTICAL FIBER PREFORM OUTER DIAMETER (mm)	1^{ST} GAS	2^{ND} GAS	DRAWING RATE (m/min)	GLASS DIAMETER FLUCTUATION (μm)	BENDING ABNORMALITY RATIO (%)	No. OF SPIKES (TIMES)	TRANSMISSION LOSS (dB/km)	RAYLEIGH SCATTERING COEFFICIENT (dBμm^4/km)
EXAMPLE3	40	N_2	AIR	400	±0. 15	0	0	0. 167	0. 835
EXAMPLE4	80	He	AIR	400	±0. 15	0	0	0. 168	0. 84
EXAMPLE5	80	He	He	400	±0. 15	0	0	0. 169	0. 845
COMPARATIVE EXAMPLE4	40	N_2	AIR	400	±0. 8	20	0	0. 168	0. 84
COMPARATIVE EXAMPLE5	40	N_2	N_2	400	±0. 15	0	12	0. 167	0. 835
COMPARATIVE EXAMPLE6	40	N_2	N_2	400	±0. 15	0	1	0. 171	0. 855

Fig.3

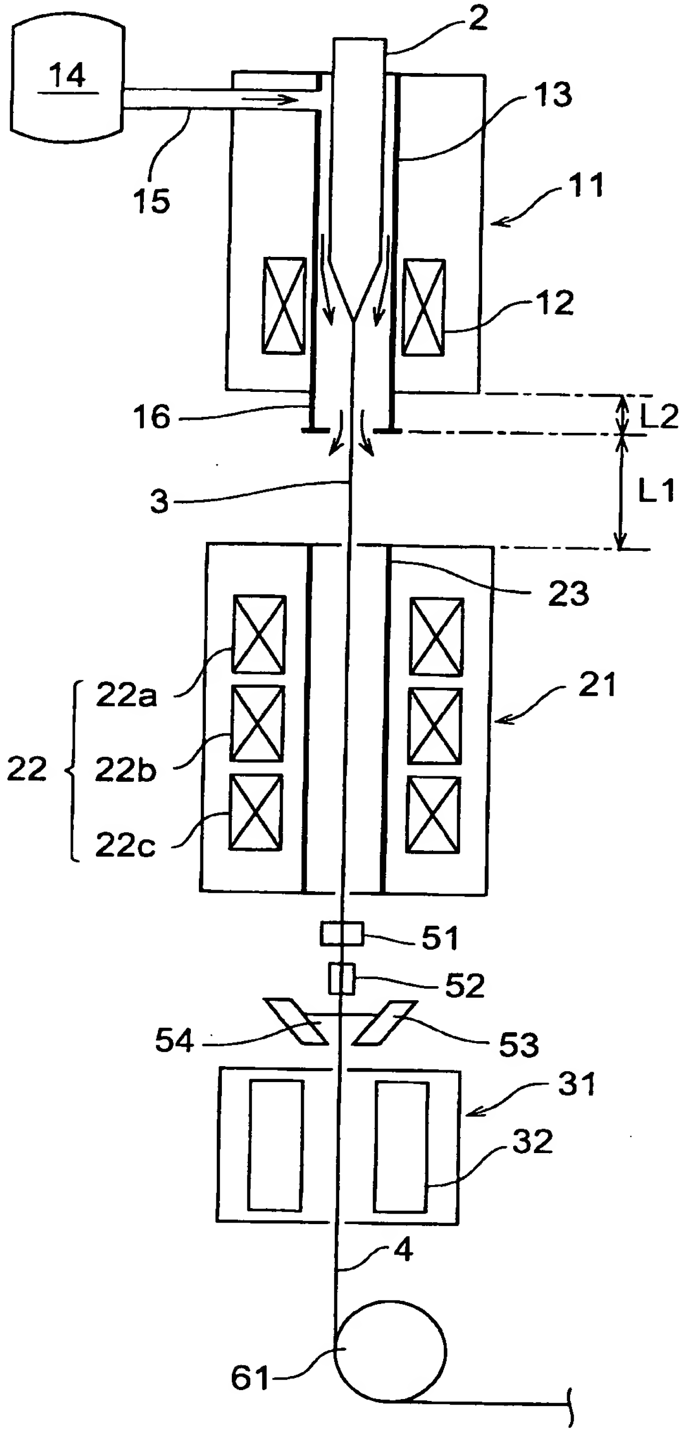


Fig.4

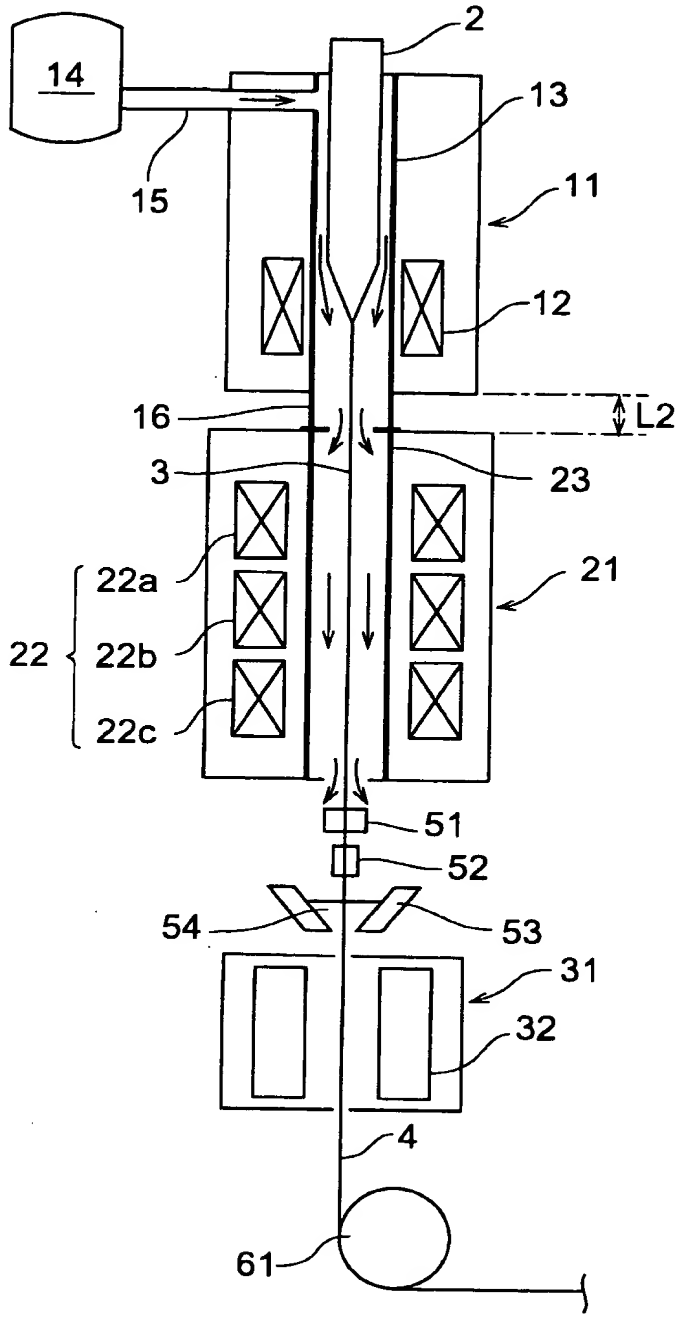
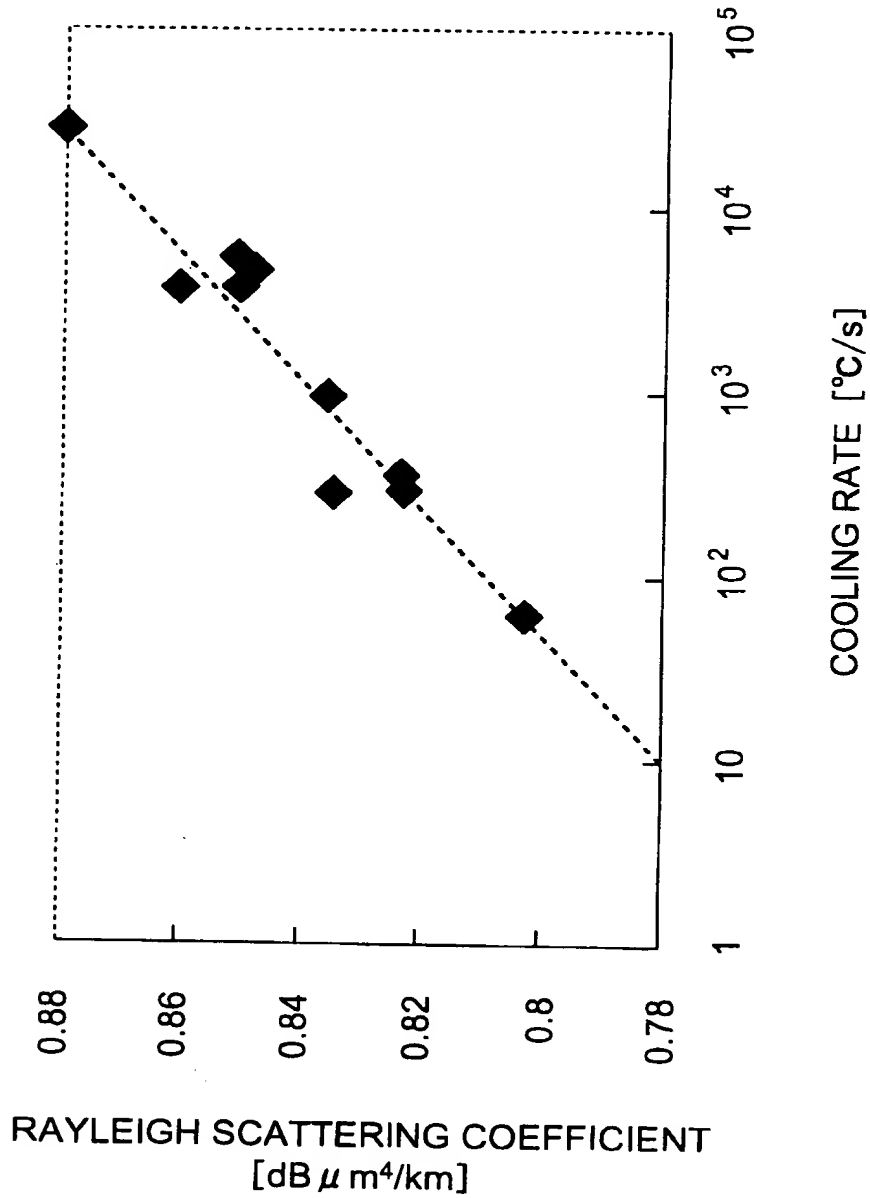


Fig.5


RAYLEIGH SCATTERING COEFFICIENT
[dB μ m⁴/km]
0.88
0.86
0.84
0.82
0.8
0.78
1
10
10^2
10^3
10^4
10^5
COOLING RATE [°C/s]

CERTIFICATE OF VERIFICATION

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state that the attached documents are a true and complete translation to the best of my knowledge of Japanese Patent Application No. 148153/1999.

Dated this 2nd day of February, 2004

Signature of translator: Shiro Terasaki

Shiro TERASAKI

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Application Number: Japanese Patent Application No.148153/1999

Applicant(s): SUMITOMO ELECTRIC INDUSTRIES, LTD.

Commissioner,
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[TYPE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] Apparatus and Method for Making Optical Fiber

[SCOPE OF CLAIMS]

[Claim 1] An apparatus for making an optical fiber, which draws an optical fiber preform upon heating and coats thus drawn optical fiber with a resin; said apparatus comprising:

a drawing furnace for drawing said optical fiber preform upon heating in an atmosphere constituted by a first gas having a predetermined thermal conductivity;

a resin coating section for coating said drawn optical fiber with said resin; and

an annealing furnace, disposed between said drawing furnace and said resin coating section, for heating and annealing said drawn optical fiber in an atmosphere constituted by a second gas having a thermal conductivity lower than said predetermined thermal conductivity of said first gas.

[Claim 2] An apparatus for making an optical fiber according to claim 1, wherein said annealing furnace is disposed with a gap with respect to said drawing furnace.

[Claim 3] An apparatus for making an optical fiber according to claim 1, wherein said first gas is He gas; and

wherein said second gas is one of N_2 gas, Ar gas, and air.

[Claim 4] An apparatus for making an optical fiber according to claim 1, wherein said annealing furnace has a muffle tube through which said drawn optical fiber passes,

said muffle tube being disposed at a position where said drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to said muffle tube.

[Claim 5] A method of making an optical fiber, which draws an optical fiber preform upon heating and coats thus drawn optical fiber with a resin; said method comprising the steps of:

drawing said optical fiber preform upon heating in an atmosphere constituted by a first gas having a predetermined thermal conductivity;

heating and annealing said drawn optical fiber in an atmosphere constituted by a second gas having a thermal conductivity lower than said predetermined thermal conductivity of said first gas;

coating said annealed optical fiber with said resin.

[Claim 6] A method of making an optical fiber according to claim 5, wherein an annealing furnace disposed with a gap with respect to a drawing furnace for drawing said optical fiber preform upon heating is used so as to anneal said drawn optical fiber in said annealing furnace.

[Claim 7] A method of making an optical fiber according to claim 5, wherein He gas is used as said first gas; and

wherein one of N_2 gas, Ar gas, and air is used as said second gas.

[Claim 8] A method of making an optical fiber according to claim 5, wherein employed as said annealing furnace is an annealing furnace having a muffle tube through which said drawn optical fiber passes, said muffle tube being disposed at a position where said drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to said muffle tube; and

wherein said drawn optical fiber is annealed in said annealing furnace.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a method and apparatus for making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[0002]

[Prior Art]

As a method of making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering loss, one disclosed in Japanese Patent Application Laid-Open No. HEI 10-25127 has been known, for example. In this manufacturing method, an optical fiber preform is drawn upon heating so as to prepare an intermediate optical fiber, which is then reheated so as to be subjected

to a heat treatment, whereby the reheating lowers the virtual temperature (the temperature to which the randomness of the state of atomic arrangement within the glass corresponds) due to the structural relaxation (rearrangement of atoms) in the glass, thus reducing its Rayleigh scattering intensity.

[0003]

[Problem to be Solved by the Invention]

However, the surface of the optical fiber immediately after drawing is coated with a UV resin or the like in order to protect the heated and drawn optical fiber. The above-mentioned method of making an optical fiber disclosed in Japanese Patent Application Laid-Open No. HEI 10-25127 is not suitable for mass-producing coated optical fibers, since the resin coated on the optical fiber surface is burned by the heat at the time of reheating. Though the optical fiber may be reheated while in an uncoated state, it is not applicable as a mass-producing method due to damages at the time of handling the optical fiber and the like.

[0004]

In view of the points mentioned above, it is an object of the present invention to provide a method and apparatus for making an optical fiber, which is applicable to the mass production of coated optical fibers whose surface is coated with a resin when making optical fibers whose transmission loss is lowered by reducing its Rayleigh scattering

intensity.

[0005]

[Means for Solving the Problem]

The inventors diligently studied apparatus and methods for making an optical fiber applicable to the mass production of coated optical fibers and, as a result, have newly found the following fact concerning the relationship between the Rayleigh scattering intensity and the cooling rate of optical fibers after drawing.

[0006]

Within the glass at a higher temperature, atoms are vigorously vibrating because of thermal energy, whereby the atomic arrangement is in a state more random than that in the glass at a lower temperature. When the glass at a higher temperature is cooled slowly, atoms are cooled while being arranged with a randomness corresponding to each temperature within the temperature range in which the atoms are allowed to be rearranged, whereby the randomness of atoms within the glass attains a state corresponding to the lowest temperature (about 1200°C) at which the structural relaxation proceeds. When the glass at a higher temperature is drastically cooled, however, it is cooled and fixed before the atomic arrangement reaches an equilibrium state corresponding to each temperature, whereby the atomic arrangement attains a state more random than that in the case annealed. The Rayleigh scattering intensity becomes

higher as the atomic arrangement is more random even in the same material. Optical fibers which are usually cooled at a cooling rate of 5000 to 30000°C/s after the drawing are presumed to have an atomic arrangement more random than that in bulk glass, which seems to increase the Rayleigh scattering intensity. At a temperature higher than 1700°C, the structural relaxation of atoms proceeds in a very short time, whereby the equilibrium state at each temperature can be maintained even when drastically cooled at about 30000°C/s.

[0007]

On the other hand, the time required for structural relaxation becomes longer as the temperature is lower, whereby the structural relaxation will not occur at a temperature on the order of 1000 to 1200°C unless the optical fiber is held at this temperature for several tens of hours, for example. Since the optical fiber after drawing is usually cooled to about 400°C within several tenths of a second, it is necessary for the optical fiber in the process of drawing to be held in a state at a temperature higher than 1200°C in order to cause structural relaxation in a short time during when the optical fiber is cooled.

[0008]

Therefore, taking account of the optical fiber temperature and cooling rate after drawing, the inventors investigated the relationship between the cooling rate and

Rayleigh scattering coefficient in a part where the temperature ranged from 1300 to 1700°C, thus being higher than the lowest temperature (about 1200°C) at which the above-mentioned structural relaxation proceeded but lower than 1700°C at which the structural relaxation proceeded in a very short period of time. As a result, it has been verified that the relationship indicated by Fig. 3 exists between the cooling rate and Rayleigh scattering coefficient in the part where the temperature of the optical fiber ranges from 1300 to 1700°C. As represented by the following expression (1), the Rayleigh scattering intensity (I) has such a property that it is inversely proportional to the fourth power of wavelength (λ):

$$I = A/\lambda^4 \qquad (1)$$

where the coefficient A is defined as the Rayleigh scattering coefficient.

[0009]

These results have proved that, if the cooling rate of an optical fiber before being coated with a resin after being drawn upon heating is slowed down, then the Rayleigh scattering intensity of the optical fiber can be reduced, so as to lower the transmission loss.

[0010]

In view of such results of studies, the present invention mentioned by the claim 1 provides an apparatus for making an optical fiber, which draws an optical fiber

preform upon heating and coats thus drawn optical fiber with a resin; the apparatus comprising a drawing furnace for drawing the optical fiber preform upon heating in an atmosphere constituted by a first gas having a predetermined thermal conductivity; a resin coating section for coating the drawn optical fiber with the resin; and an annealing furnace, disposed between the drawing furnace and the resin coating section, for heating and annealing the drawn optical fiber in an atmosphere constituted by a second gas having a thermal conductivity lower than the predetermined thermal conductivity of the first gas.

[0011]

Since the apparatus for making an optical fiber according to claim 1 mentioned above comprises an annealing furnace, disposed between the drawing furnace and the resin coating section, for heating and annealing the optical fiber drawn in an atmosphere constituted by the second gas having a thermal conductivity lower than the predetermined thermal conductivity of the first gas, the thermal conductivity of the atmosphere gas for the optical fiber within the annealing furnace is lowered, so that the cooling rate of the optical fiber before being coated with a resin after being drawn upon heating is slowed down in a predetermined segment, whereby the optical fiber is annealed. Therefore, the structural relaxation of the optical fiber proceeds in a short time, so that the randomness in atomic arrangement

is reduced, whereby it is possible to make, in a very short period of time from the drawing upon heating to the resin coating, an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity. Since the Rayleigh scattering intensity is reduced by controlling the cooling rate of the optical fiber before being coated with a resin after being drawn, the heat treatment for reheating such as that in the above-mentioned prior art is unnecessary, whereby the apparatus can be applied quite easily to the mass production of coated optical fibers whose surface is coated with a resin. Also, since the atmosphere gas for the optical fiber within the drawing furnace has a thermal conductivity higher than that of the second gas acting as the atmosphere gas within the annealing furnace, the optical fiber preform is softened upon heating and rapidly cooled until it approximates a predetermined diameter, whereby the outer diameter of optical fiber can be restrained from fluctuating.

[0012]

It is preferable that the annealing furnace is disposed with a gap with respect to the drawing furnace. Thus, providing a gap between the annealing furnace and the drawing furnace suppresses the occurrence of such a state that the first gas flows into the annealing furnace side or the second gas flows into the drawing furnace side, whereby the thermal conductivity of atmosphere gas within the drawing furnace

and the thermal conductivity of atmosphere gas within the annealing furnace are maintained appropriately. Therefore, it becomes possible to stably make an optical fiber whose transmission loss is lowered while its outer diameter is restrained from fluctuating.

[0013]

Alternatively, it is preferable that the first gas is He gas, whereas the second gas is one of N_2 gas, Ar gas, and air. Thus, when the first gas is He gas while the second gas is one of N_2 gas, Ar gas, and air, the thermal conductivity of atmosphere gas within the drawing furnace and the thermal conductivity of atmosphere gas within the annealing furnace can be set to appropriate values.

[0014]

Alternatively, it is preferable that the annealing furnace has a muffle tube for passing the drawn optical fiber therethrough, whereas the muffle tube is disposed at a position where the drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to the muffle tube. Thus, when the annealing furnace is disposed at a position where the drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to the muffle tube, the cooling rate of the optical fiber in a part attaining a temperature of 1300 to 1700°C is slowed down in a predetermined segment, whereby the virtual temperature of the optical fiber is further

lowered, which makes it possible to further reduce the Rayleigh scattering intensity.

[0015]

The present invention mentioned by the claim 5 provides a method of making an optical fiber, which draws an optical fiber preform upon heating and coats thus drawn optical fiber with a resin; the method comprising the steps of drawing the optical fiber preform upon heating in an atmosphere constituted by a first gas having a predetermined thermal conductivity; heating and annealing the drawn optical fiber in an atmosphere constituted by a second gas having a thermal conductivity lower than the predetermined thermal conductivity of the first gas; coating the annealed optical fiber with the resin.

[0016]

Since the method of making an optical fiber according to claim 5 mentioned above draws the optical fiber upon heating in an atmosphere constituted by the first gas, and then heats and anneals the drawn optical fiber in an atmosphere constituted by the second gas having a thermal conductivity lower than the predetermined thermal conductivity of the first gas, the cooling rate of the optical fiber before being coated with the resin after being drawn upon heating is slowed down in a predetermined segment. Therefore, the structural relaxation of the optical fiber proceeds in a short time, so that the randomness in atomic

arrangement is reduced, whereby it is possible to make, in a short period of time from the drawing upon heating to the resin coating, an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity. Since the Rayleigh scattering intensity is reduced by controlling the cooling rate of the optical fiber before being coated with a resin after being drawn, the heat treatment for reheating such as that in the above-mentioned prior art is unnecessary, whereby the method can be applied quite easily to the mass production of coated optical fibers whose surface is coated with a resin. Also, since the optical fiber preform is drawn upon heating in an atmosphere gas constituted by the first gas having a thermal conductivity higher than that of the second gas, the optical fiber preform is softened upon heating and rapidly cooled until it approximates a predetermined diameter, whereby the outer diameter of optical fiber can be restrained from fluctuating.

[0017]

It is preferable that the annealing furnace disposed with a predetermined distance with respect to the drawing furnace for drawing the optical fiber preform upon heating is used, so as to anneal the drawn optical fiber in the annealing furnace. Thus, using the annealing furnace disposed with a predetermined distance with respect to the drawing furnace suppresses the occurrence of such a state that the first gas flows into the annealing furnace side

or the second gas flows into the drawing furnace side, whereby the thermal conductivity of atmosphere gas within the drawing furnace and the thermal conductivity of atmosphere gas within the annealing furnace are maintained appropriately. Therefore, it becomes possible to stably make an optical fiber whose transmission loss is lowered while its outer diameter is restrained from fluctuating.

[0018]

Alternatively, it is preferable that He gas is used as the first gas, whereas one of N_2 gas, Ar gas, and air is used as the second gas. Thus, when He gas is used as the first gas while one of N_2 gas, Ar gas, and air is used as the second gas, the thermal conductivity of atmosphere gas within the drawing furnace and the thermal conductivity of atmosphere gas within the annealing furnace can be set to appropriate values.

[0019]

Alternatively, it is preferable that as the annealing furnace, an annealing furnace having a muffle tube disposed at a position where the drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to the muffle tube is used, so as to anneal the drawn optical fiber in the annealing furnace. Thus, when the annealing furnace disposed at a position where the drawn optical fiber has an entering temperature within the range of 1400 to 1800°C with respect to the muffle tube is used, the cooling rate

of the optical fiber in a part attaining a temperature of 1300 to 1700°C can be slowed down in a predetermined segment, whereby the virtual temperature of the optical fiber is further lowered, which makes it possible to further reduce the Rayleigh scattering intensity.

[0020]

[Embodiments of the Invention]

Hereinafter, embodiments of the present invention will be explained with reference to the accompanying drawings.

[0021]

To begin with, a embodiment of the apparatus for making an optical fiber and a drawing apparatus used for the making method in accordance with the present invention will be explained with reference to Fig. 1.

[0022]

A drawing apparatus 1 is a drawing apparatus for silica type optical fibers, having a drawing furnace 11, an annealing furnace 21, and a resin curing section 31 which are disposed in this order in the drawing direction of an optical fiber preform 2 (downward in Fig. 1). The optical fiber preform 2 held by a preform supply apparatus (not depicted) is supplied to the drawing furnace 11, and the lower end of the optical fiber preform 2 is heated and softened by a heater 12 within the drawing furnace 11, whereby an optical fiber 3 is drawn. The drawing furnace 11 has a muffle

tube 13 configured such that an He gas supply passage 15 from an He gas supply section 14 is connected thereto, so as to supply He gas as a first gas into the muffle tube 13 of the drawing furnace 11, whereby an He gas atmosphere is attained within the muffle tube 13. The optical fiber 3 drawn upon heating is drastically cooled to about 1700°C within the muffle tube 13. Thereafter, the optical fiber 3 is let out of the drawing furnace 11 from the lower part of the muffle tube 13, and is cooled with air between the drawing furnace 11 and the annealing furnace 21. The thermal conductivity λ (T = 300 K) of He gas is 150 mW/(m·K), whereas the thermal conductivity λ (T = 300 K) of air is 26 mW/(m·K).

[0023]

The air-cooled optical fiber 3 is fed to the annealing furnace 21, whereby a predetermined segment of the optical fiber 3 is heated and then is annealed at a predetermined cooling rate. The annealing furnace 21 has a muffle tube 23 through which the optical fiber 3 passes, whereas the muffle tube 23 is set such that the total length L2 (m) of the optical fiber preform 2 in the drawing direction of the optical fiber preform 2 (the vertical direction in Fig. 1) satisfies:

$$L2 \geq V/8 \qquad (2)$$

where V is the drawing rate (m/s). Also, the annealing furnace 21 is disposed such that the muffle tube 23 is set at a position where the optical fiber immediately before

entering the muffle tube 23 has a temperature (entering temperature) within the range of 1400 to 1800°C, while satisfying the following relationship with respect to the drawing furnace 11:

$$L1 \leq 0.2 \times V \qquad (3)$$

where L1 is the distance (m) from the lower end of the heater 12 in the drawing furnace 11 to the upper end of the muffle tube 23, and V is the drawing rate (m/s). The temperature of a heater 22 in the annealing furnace 21 is set such that the inner peripheral face of the muffle tube 23 (the surface facing the surface of the optical fiber preform 2 or optical fiber 3) attains a surface temperature within the range of 1200 to 1600°C, 1300 to 1500°C in particular.

[0024]

When the position and length of the annealing furnace 21 (muffle tube 23) are set as mentioned above, a segment where the optical fiber 3 drawn upon heating yields a temperature difference of 50°C or more, e.g., a part where the temperature of the optical fiber 3 ranges from 1400 to 1600°C (a segment yielding a temperature difference of 200°C), in a portion where the temperature of the optical fiber 3 ranges from 1300 to 1700°C is annealed at a cooling rate of 1000°C/s or less. When the surface temperature of inner peripheral face of the muffle tube 23 (the surface facing the surface of the optical fiber preform 2 or optical fiber 3) is set to a temperature within the range of 1300 to 1500°C,

a segment where the optical fiber 3 drawn upon heating yields a temperature difference of 50°C or more in a portion where the temperature of the optical fiber 3 ranges from 1400 to 1600°C is annealed at a cooling rate of 1000°C/s or less.

[0025]

The muffle tube 23 of the annealing furnace 21 is configured such that an N_2 gas supply passage 25 from an N_2 gas supply section 24 is connected thereto, so as to supply N_2 gas as a second gas into the muffle tube 23 of the annealing furnace 21, whereby an N_2 gas atmosphere is attained within the muffle tube 23. N_2 gas has a thermal conductivity lower than that of He gas, thereby acting to slow down the cooling rate of optical fiber. The thermal conductivity λ ($T = 300$ K) of N_2 gas is 26 mW/(m·K). A gas having a relatively high molecular weight such as air or Ar, and the like can be used in place of N_2 gas. When a carbon heater is employed, it is necessary to use an inert gas as a matter of course.

[0026]

The outer diameter of the optical fiber 3 let out of the annealing furnace 21 is measured online by an outer diameter meter 41 acting as outer diameter measuring means, and its measured value is fed back to a driving motor 43 for driving a drum 42 to rotate, whereby the outer diameter is controlled so as to become constant. An output signal from the outer diameter meter 41 is fed to a control unit 44 acting as control means, and the rotating speed of the

drum 42 (driving motor 43) is determined by an arithmetic operation such that the outer diameter of the optical fiber 3 attains a predetermined value which has been set beforehand. From the control unit 44, an output signal indicative of the rotating speed of the drum 42 (driving motor 43) determined by the arithmetic operation is fed to a driving motor driver (not depicted). According to the output signal from the control unit 44, the driving motor driver controls the rotating speed of the driving motor 43.

[0027]

Thereafter, a coating die 51 coats the optical fiber 3 with a UV resin 52, and a UV lamp 32 in the resin curing section 31 cures the UV resin 52, thereby yielding a coated optical fiber 4. Then, by way of a guide roller 61, the coated optical fiber 4 is taken up by the drum 42. The drum 42 is supported by a rotary driving shaft 45, whereas an end part of the rotary driving shaft 45 is connected to the driving motor 43. Here, the coating die 51 and resin curing section 31 constitute the resin coating section in each claim. The resin coating section may be configured so as to apply a thermosetting resin, which is then cured by the annealing furnace.

[0028]

Results of experiments carried out by using the above-mentioned drawing apparatus 1 (where the drawing furnace 11 has a lower extension with a length (L3) of 0.07

m) will now be explained. These experiments have the following common conditions. As the optical fiber preform 2, one having an outer diameter of 50 mm was used, and an optical fiber 3 having an outer diameter of 125 μm was drawn from the optical fiber preform 2. The temperature of the drawing furnace was such that the surface temperature of the inner peripheral face of the muffle tube was about 2000°C. In the following experimental examples (Examples 1 and 2 and Comparative Examples 1 to 3), the temperature of the optical fiber 3 refers to the surface temperature of the optical fiber 3. The difference in temperature between the surface of the optical fiber 3 and the inside thereof is about 20 to 50°C. The temperatures of the drawing furnace 11 and the annealing furnace 21 refer to the surface temperatures of the inner peripheral faces of the muffle tubes 13, 23 (facing the surface of the optical fiber preform 2 or optical fiber 3).

[0029]

Examples 1 and 2 are examples in conformity to the method for making a silica type optical fiber in accordance with the above-mentioned embodiment, whereas Comparative Examples 1 to 3 are comparative examples carried out for comparison with the above-mentioned Examples in conformity to the apparatus and method for making an optical fiber in accordance with the embodiment.

[0030]

(Example 1)

Using an annealing furnace having a muffle tube (with an inner peripheral diameter of about 30 mm) in which L1 = 0.4 m and L2 = 1.0 m, an optical fiber was drawn. The distance (L4) between the drawing furnace and the annealing furnace was set to 0.05 m. The optical fiber preform to be drawn had a core portion constituted by pure silica glass, and a cladding portion constituted by fluorine-doped glass. The drawing rate was 4 m/s, the drawing tension was 25 gf, and the temperature of the annealing furnace (the surface temperature of the inner peripheral face of the muffle tube) was 1400°C. The temperature (entering temperature) of the optical fiber immediately before entering the annealing furnace was about 1600°C in terms of the surface temperature of optical fiber. As can be seen from characteristic (a) in Fig. 2, the optical fiber had such a temperature distribution (calculated value) that it was annealed as being held at a temperature of 1600°C or thereabout within the annealing furnace 21. Here, in the annealing furnace, a part of the drawn optical fiber where the temperature ranged from 1550 to 1650°C was supposed to have been cooled at an annealing rate of about 600 to 800°C/s in a segment of 1.0 m which was the total length of the annealing furnace. As shown in Fig. 3a, a forcible cooling section 71 was provided with a gap with respect to the annealing furnace, whereby the annealed optical fiber 3 was forcibly cooled in the

forcible cooling section 71.

[0031]

Upon measurement, the transmission loss (with respect to light having a wavelength of 1.55 μm) of the drawn optical fiber was 0.170 dB/km. The Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.84 dBμm^4/km. The outer diameter of the drawn optical fiber was 125±0.1 μm.

[0032]

(Example 2)

Using an annealing furnace having a muffle tube (with an inner peripheral diameter of about 30 mm) in which L1 = 0.4 m and L2 = 2.0 m, an optical fiber was drawn. The distance (L4) between the drawing furnace and the annealing furnace was set to 0.05 m. The optical fiber preform to be drawn had a core portion constituted by Ge-doped silica glass, and a cladding portion constituted by silica glass. The relative refractive index difference Δn between the core portion and cladding portion was 0.36%. The drawing rate was 8 m/s, the drawing tension was 80 gf, and the temperature of the annealing furnace (the surface temperature of the inner peripheral face of the muffle tube) was 1400°C. The temperature (entering temperature) of the optical fiber immediately before entering the annealing furnace was about 1600°C in terms of the surface temperature of optical fiber. Here, in the annealing furnace, a part of the drawn optical

fiber where the temperature ranged from 1500 to 1600°C was supposed to have been cooled at an annealing rate of about 500 to 700°C/s in a segment of 2.0 m which was the total length of the annealing furnace.

[0033]

Upon measurement, the transmission loss (with respect to light having a wavelength of 1.55 μm) of the drawn optical fiber was 0.182 dB/km. The Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.92 dBμm^4/km. The outer diameter of the drawn optical fiber was 125±0.1 μm.

[0034]

(Comparative Example 1)

Using an annealing furnace having a muffle tube (with an inner peripheral diameter of about 30 mm) in which L1 = 0.4 m and L2 = 1.0 m, an optical fiber was drawn. The distance (L4) between the drawing furnace and the annealing furnace was set to 0.05 m. The optical fiber preform to be drawn had a core portion constituted by pure silica glass, and a cladding portion constituted by fluorine-doped silica glass. The drawing rate was 4 m/s, and the drawing tension was 25 gf. No heating was carried out in the annealing furnace, whereas He gas was supplied into the annealing furnace (muffle tube) instead of N_2 gas. As can be seen from characteristic (c) in Fig. 2, the temperature distribution (calculated value) of the optical fiber was

such that the optical fiber let out of the drawing furnace was cooled at a cooling rate of about 30000°C/s.

[0035]

Upon measurement, the transmission loss (with respect to light having a wavelength of 1.55 μm) of the drawn optical fiber was 0.18 dB/km. The Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.9 dBμm^4/km.

[0036]

(Comparative Example 2)

Using an annealing furnace having a muffle tube (with an inner peripheral diameter of about 30 mm) in which L1 = 0.4 m and L2 = 1.0 m, an optical fiber was drawn. The distance (L4) between the drawing furnace and the annealing furnace was set to 0.05 m. The optical fiber preform to be drawn had a core portion constituted by pure silica glass, and a cladding portion constituted by fluorine-doped silica glass. The drawing rate was 4 m/s, and the drawing tension was 25 gf. No heating was carried out in the annealing furnace. N_2 gas was supplied into the annealing furnace (muffle tube). As indicated by characteristic (c) in Fig. 2, the temperature distribution (calculated value) of the optical fiber was such that the optical fiber let out of the drawing furnace was cooled at a cooling rate of about 4000 to 5000°C/s.

[0037]

Upon measurement, the transmission loss (with respect to light having a wavelength of 1.55 μm) of the drawn optical fiber was 0.174 dB/km. The Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.86 dBμm^4/km.

[0038]

(Comparative Example 3)

Using an annealing furnace having a muffle tube (with an inner peripheral diameter of about 30 mm) in which L1 = 0.4 m and L2 = 1.0 m, an optical fiber was drawn. The distance (L4) between the drawing furnace and the annealing furnace was set to 0.05 m. The optical fiber preform to be drawn had a core portion constituted by pure silica glass, and a cladding portion constituted by fluorine-doped silica glass. The drawing rate was 4 m/s, the drawing tension was gf, and the temperature of the annealing furnace (the surface temperature of the inner peripheral face of the muffle tube) was 1400°C. N_2 gas was supplied into the annealing furnace (muffle tube) instead of He gas.

[0039]

Upon measurement, the transmission loss (with respect to light having a wavelength of 1.55 μm) of the drawn optical fiber was 0.170 dB/km. The Rayleigh scattering coefficient determined from measured data of wavelength characteristics of transmission loss was 0.84 dBμm^4/km. The outer diameter of the drawn optical fiber was 125±0.3 μm.

[0040]

As in the foregoing, Example 1 yielded a Rayleigh scattering coefficient of 0.84 dBμm^4/km and a transmission loss of 0.17 dB/km with respect to light having a wavelength of 1.55 μm, so that the transmission loss was reduced by lowering the Rayleigh scattering loss as compared with Comparative Examples 1 and 2 yielding a Rayleigh scattering coefficient of 0.86 to 0.9 dBμm^4/km and a transmission loss of 0.174 to 0.18 dB/km with respect to light having a wavelength of 1.55 μm in Comparative Examples 1 and 2. On the other hand, Example 2 yielded a Rayleigh scattering coefficient of 0.92 dBμm^4/km and a transmission loss of 0.182 dB/km with respect to light having a wavelength of 1.55 μm, thereby fully reducing the transmission loss as a Ge-containing single-mode optical fiber.

[0041]

In Examples 1 and 2, the outer diameter of the drawn optical fiber was 125±0.1 μm, whereby the fluctuation in outer diameter of the optical fiber was suppressed as compared with that of 125±0.3 μm in Comparative Example 3, whereby stable drawing was possible.

[0042]

Thus, as can be seen from the results of experiments mentioned above, the annealing furnace 21 for heating a predetermined segment of the optical fiber 3 and annealing it at a predetermined cooling rate is disposed between the

drawing furnace 11 and the resin curing section 31 (coating die 51), the He gas supply passage 15 from the He gas supply section 14 is connected to the core tube 13 of the drawing furnace 11 so as to supply He gas into the core tube 13, and the N_2 gas supply passage 25 from the N_2 gas supply section 24 is connected to the core tube 23 of the annealing furnace 21 so as to supply N_2 gas into the core tube 23, whereby an He gas atmosphere is attained within the core tube 13 while an N_2 gas atmosphere is attained within the core tube 23 in the apparatus and method for making an optical fiber in accordance with this embodiment. Therefore, the atmosphere gas for the optical fiber 3 within the annealing furnace 21 has a lower thermal conductivity (N_2 gas yields a thermal conductivity λ ($T = 300$ K) of 26 mW/(m·K)), so that the cooling rate of the optical fiber before being coated with the UV resin 52 after being drawn upon heating is slowed down in a predetermined segment, whereby the structural relaxation proceeds in a short time, thus reducing the randomness in atomic arrangement. Consequently, it is possible to make, in a very short period of time between the drawing upon heating and the coating with the UV resin 52, the optical fiber 3 whose transmission loss is reduced by lowering its Rayleigh scattering intensity. Since the Rayleigh scattering intensity is reduced by controlling the cooling rate of the optical fiber 3 before being coated with the UV resin 52 after being drawn, the heat treatment for

reheating such as that in the above-mentioned prior art is unnecessary, whereby this embodiment can be applied quite easily to the mass production of the coated optical fiber 4 whose surface is coated with the UV resin 52 cured thereon. Also, since the atmosphere gas for the optical fiber preform 2 and optical fiber 3 within the drawing furnace 11 has a thermal conductivity higher than that of the atmosphere gas within the heating furnace (He gas yields a thermal conductivity λ ($T = 300$ K) of 150 mW/(m·K)), the optical fiber preform 2 is softened upon heating and rapidly cooled until it approximates a predetermined diameter, whereby the outer diameter of optical fiber 3 can be restrained from fluctuating.

[0043]

Since the annealing furnace 21 is disposed with a gap with respect to the drawing furnace 11, so that the optical fiber 3 is let out of the drawing furnace 11 from the lower part of the muffle tube 13 and is cooled with air between the drawing furnace 11 and annealing furnace 21 before entering the annealing furnace 21, the occurrence of such a state that He gas flows into the annealing furnace 21 (into the muffle tube 23) or N_2 gas flows into the drawing furnace 11 (into the muffle tube 13) is suppressed, whereby the thermal conductivity of He gas within the drawing furnace 11 and the thermal conductivity of N_2 gas within the annealing furnace 21 are maintained appropriately. As a consequence,

the optical fiber 3 whose transmission loss is lowered while its outer diameter is restrained from fluctuating can be made stably.

[0044]

When the core tube 23 of the heating furnace 21 is located at a position where the temperature (entering temperature) of the optical fiber immediately before entering the core tube 23 falls within the range of 1400 to 1800°C, a predetermined segment of the portion of optical fiber 3 yielding a temperature of 1300 to 1700°C before being coated with the UV resin 52 can securely be heated, so as to appropriately slow down the cooling rate in this portion. Since the cooling rate is slowed down in a predetermined segment in the portion of optical fiber 3 yielding a temperature of 1300 to 1700°C, the structural relaxation of the optical fiber 3 is promoted, whereby the Rayleigh scattering intensity can further be reduced.

[0045]

When the muffle tube 23 of the annealing furnace 21 is located at a position satisfying the above-mentioned expression (3), a predetermined segment of the portion of optical fiber 3 yielding a temperature of 1300 to 1700°C before being coated with the UV resin 52 after being drawn upon heating in the drawing furnace 11 can securely be heated, so as to appropriately slow down the cooling rate in this portion.

[0046]

When the muffle tube 23 of the annealing furnace 21 has a total length satisfying the above-mentioned expression (2), a predetermined segment of the portion of optical fiber 3 yielding a temperature of 1300 to 1700°C before being coated with the UV resin 52 after being drawn upon heating in the drawing furnace 11 can securely be heated, so as to appropriately slow down the cooling rate in this portion.

[0047]

Since the He gas atmosphere is attained within the muffle tube 13 of the drawing furnace 11 while the optical fiber 3 is cooled with air between the drawing furnace 11 and the annealing furnace 21 such that its part before entering the annealing furnace 21 (the part of optical fiber 3 yielding a temperature of 1700°C or higher) is cooled at a cooling rate of 4000°C/s or higher, the height of equipment required for cooling the optical fiber 3 can be lowered when the drawing speed is high. Since the structural relaxation of atoms proceeds in a very short period of time at a temperature higher than 1700°C, the equilibrium state at each temperature can be maintained even when cooled at a cooling rate of 4000°C/s or higher, which exerts no influence on the Rayleigh scattering intensity.

[0048]

Since the outer diameter meter 41 for measuring the outer diameter of the optical fiber 3 let out of the annealing

furnace 21 and the control unit 44 for controlling the rotating speed of the drum 42 (driving motor 43) in response to the output signal from the outer diameter meter 41 such that the outer diameter of the optical fiber 3 attains a predetermined value are provided, the outer diameter of the optical fiber 3, whose outer diameter length is in a stable state, let out of the annealing furnace 21 can be measured, so that the rotating speed of the drum 42 (driving motor 43) can be controlled according to this stable outer diameter, whereby the drawing speed of the optical fiber 3 can be controlled appropriately.

[0049]

As a modified example of the embodiment, the heater 22 of the annealing furnace 21 may be constituted by a plurality of heaters, which are arranged in the direction of drawing the optical fiber preform (downward in Fig. 1) so as to yield such a temperature gradient that a higher temperature is attained on the drawing furnace 11 side whereas a lower temperature is attained on the resin curing section 31 (coating die 51) side. The optical fiber 3 drawn upon heating in the drawing furnace 11 has such a temperature distribution that the temperature decreases from the drawing furnace 11 side to the resin curing section 31 (coating die 51) side. Therefore, when a plurality of heaters are provided so as to yield such a temperature gradient that a higher temperature is attained on the drawing furnace 11

side whereas a lower temperature is attained on the resin curing section 31 (coating die 51) side, the inside of the muffle tube 23 has a temperature distribution corresponding to the temperature of the optical fiber 3, thereby appropriately keeping the temperature difference with respect to the optical fiber 3, which makes it possible to cool the optical fiber 3 at a further suitable cooling rate.

[0050]

As another modified example, the annealing furnace 21 may be provided integrally with the drawing furnace 11 in a continuous fashion. The case where the annealing furnace 21 is provided integrally with the drawing furnace 11 in a continuous fashion as such also enables the making of the optical fiber 3 whose transmission loss is reduced by lowering the Rayleigh scattering coefficient.

[0051]

[Effects of the Invention]

As explained in detail in the foregoing, the present invention can provide an apparatus and method for making an optical fiber, which is applicable to the mass production of coated optical fibers whose surface is coated with a resin, when making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A schematic diagram showing an embodiment of the

apparatus for making an optical fiber in accordance with the present invention.

[Fig. 2]

A chart showing the temperature distribution of an optical fiber in an embodiment of the apparatus for making an optical fiber in accordance with the present invention.

[Fig. 3]

A chart showing the relationship between Rayleigh scattering coefficient and optical fiber cooling rate.

[DESCRIPTION OF THE NUMERALS]

1 ··· a drawing apparatus, 2,102 ··· an optical fiber preform, 3 ··· an optical fiber, 4 ··· a coated optical fiber, 11 ··· a drawing furnace, 12 ··· a heater, 13 ··· a muffle tube, 14 ··· an He gas supply section, 15 ··· an He gas supply passage, 21 ··· an annealing furnace, 22 ··· a heater, 23 ··· a muffle tube, 24 ··· an N_2 gas supply section, 25 ··· an N_2 gas supply passage, 31 ··· a resin curing section, 32 ··· a UV lamp, 41 ··· an outer diameter meter, 42 ··· a drum, 43 ··· a driving motor, 44 ··· a control unit, 45 ··· a rotary driving shaft, 51 ··· a coating die, 52 ··· a UV resin, 61 ··· a guide roller.

[TYPE OF DOCUMENT] ABSTRACT

[ABSTRACT]

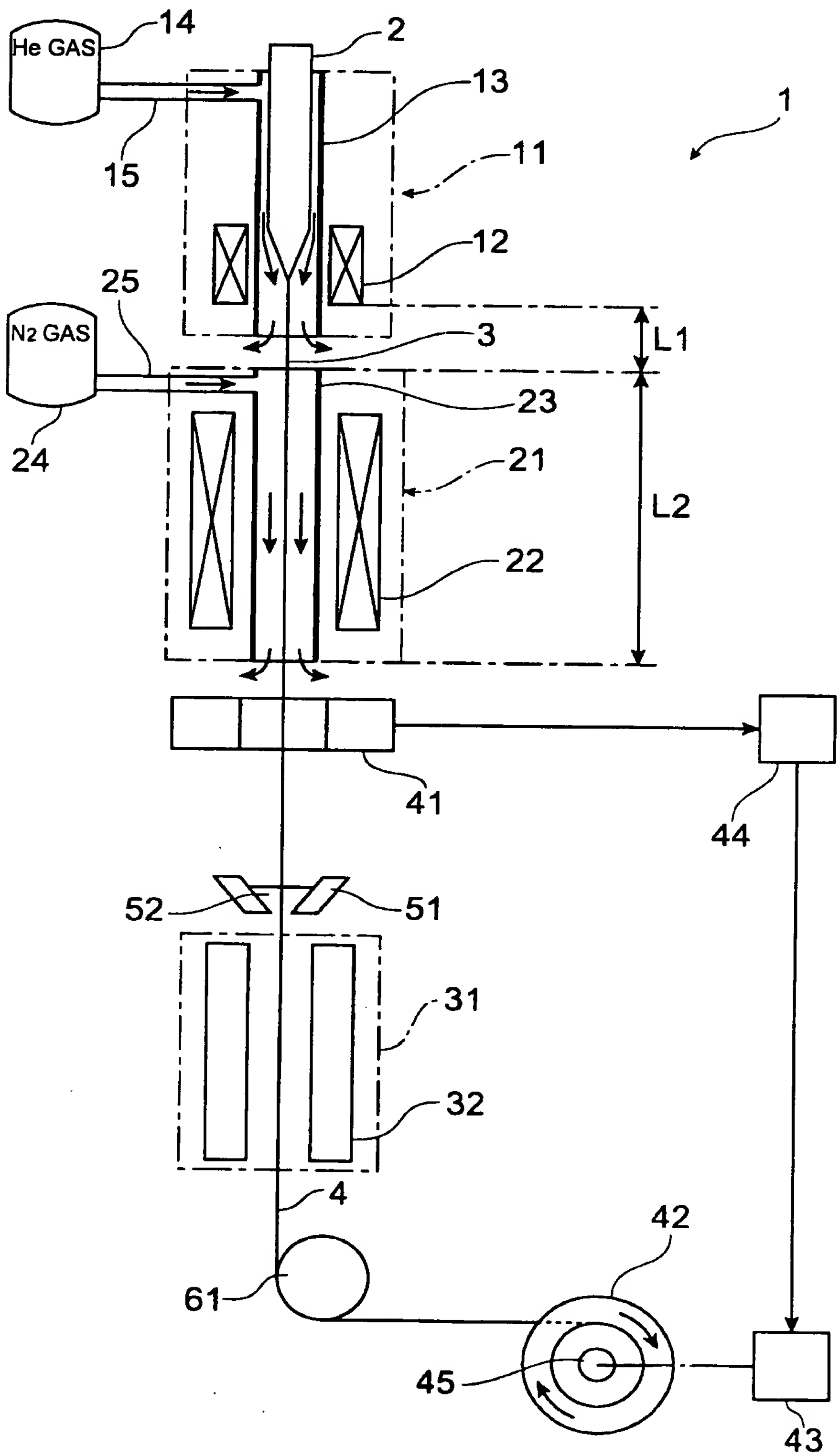
[Problem] To provide a method for making an optical fiber, which is applicable to the mass production of coated optical fibers whose surface is coated with a resin, when making an optical fiber whose transmission loss is lowered by reducing its Rayleigh scattering intensity.

[Solving Means] A drawing apparatus 1 has a drawing furnace 11, an annealing furnace 21, and a resin curing section 31. The drawing furnace 11 has a core tube 13 to which an He gas supply passage 15 from an He gas supply section 14 is connected so as to supply He gas. The optical fiber 3 drawn upon heating by the drawing furnace 11 is fed to the annealing furnace 21, whereby a predetermined part of the optical fiber 3 is annealed at a predetermined cooling rate. The annealing furnace 21 has a core tube 23 to which an N_2 gas supply passage 25 from an N_2 gas supply section 24 is connected so as to supply N_2 gas. Thereafter, the optical fiber 3 is coated with a coating resin solution 52 by a primary coating die 51, and the coating resin is heated to cure in the resin curing section 31, whereby a coated optical fiber 4 is formed.

[ELECTED FIGURE] Fig. 1

【TYPE OF DOCUMENT】 1/3
DORAWING

Fig.1



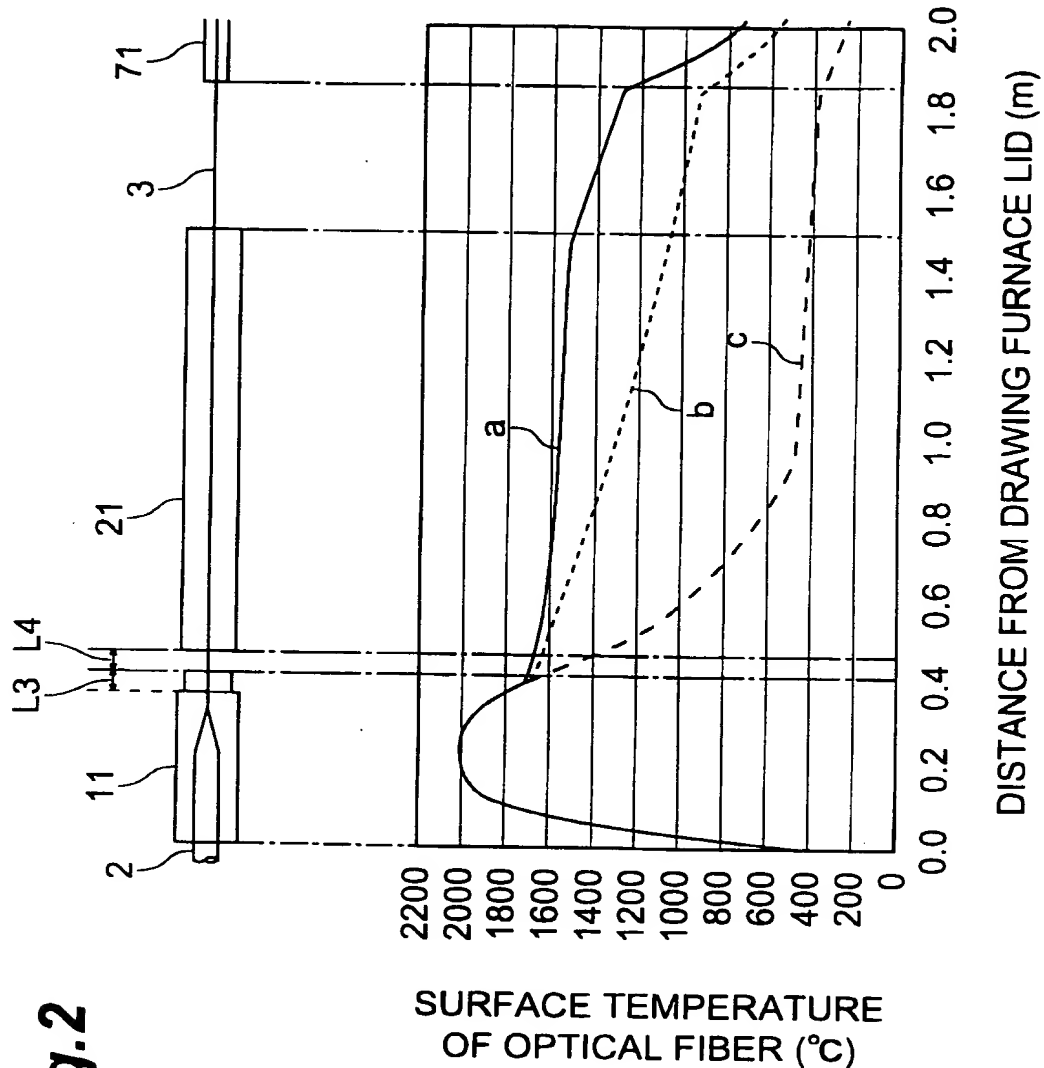
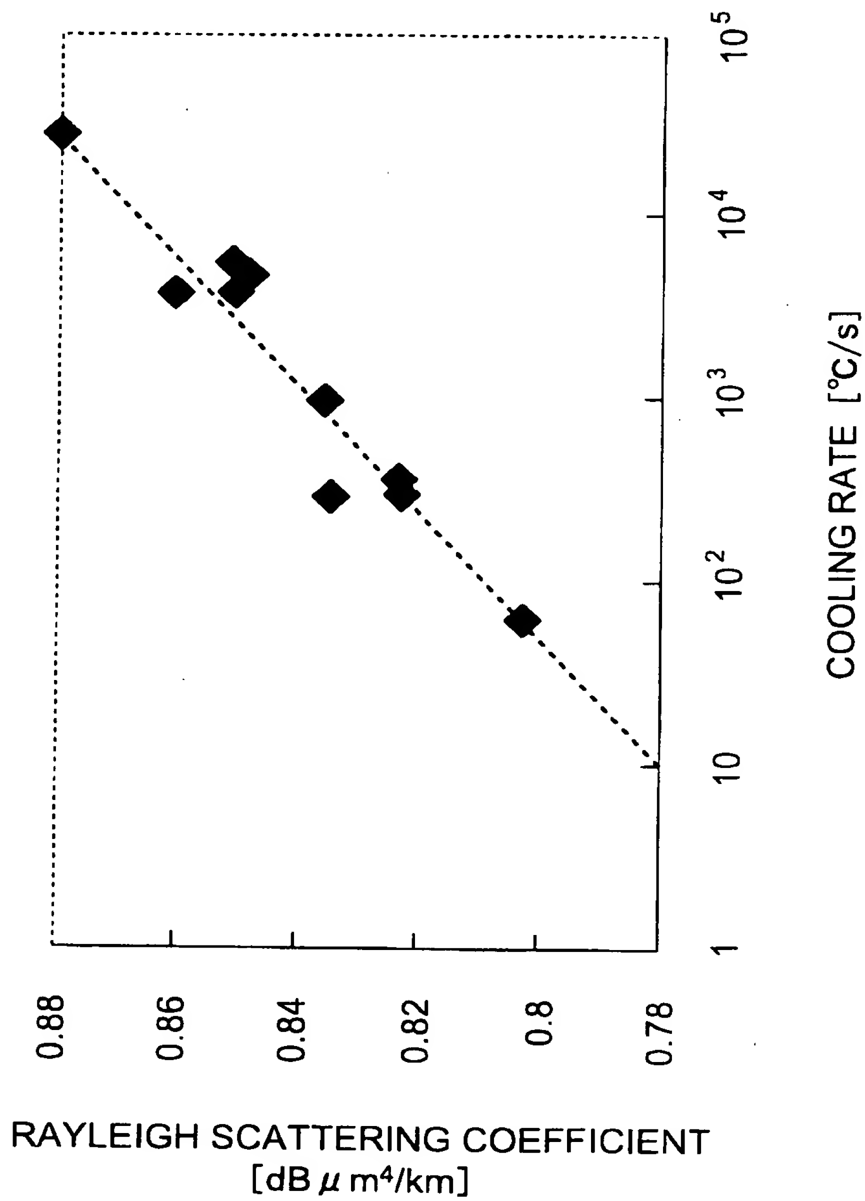
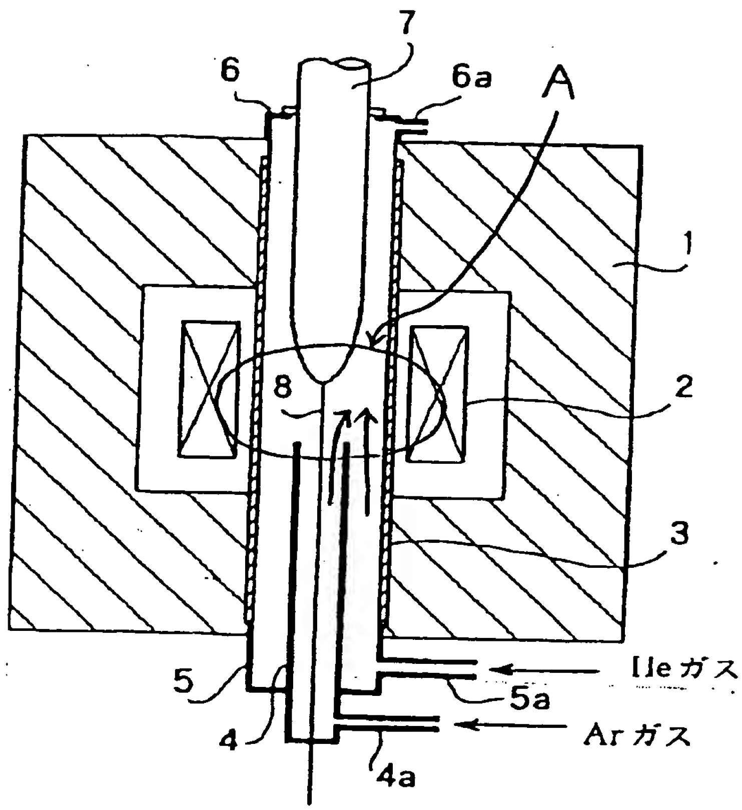

71
3
21
L3 L4
11
2
a
b
c
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DISTANCE FROM DRAWING FURNACE LID (m)
SURFACE TEMPERATURE OF OPTICAL FIBER (°C)

Fig.2

Fig.3


0.88
0.86
0.84
0.82
0.8
0.78
1
10
10^2
10^3
10^4
10^5
COOLING RATE [°C/s]
RAYLEIGH SCATTERING COEFFICIENT
[dB μ m⁴/km]


7
6
6a
A
1
2
8
3
Heガス
5
5a
4
Arガス
4a